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INDICATOR SIGNIFICANCE OF THE NATURAL VEGETATION OF THE SOUTHWESTERN DESERT REGION [1]

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The natural plant cover, if properly interpreted, indicates the crop-producing capabilities of land as well, if not better, than any series of meteorological observations or soil analyses. The value of the soil and climatic studies is not minimized by this statement, since it is only through a study of soil and meteorological conditions that the significance of the vegetation can be interpreted, especially where agriculture is not already well established.

Slight differences in either soil or climate may produce profound changes in the vegetation type, and, conversely, changes in the vegetation type may indicate only slight differences in soil or climatic conditions.

A description of the types of vegetation forms an important and necessary part of any adequate study of an agricultural region. In this paper the writers are not concerned with a descriptive or geographic study of any particular region, but with a determination of the soil and climatic conditions which are indicated by different types of natural vegetation. In other words, what are the conditions which have led to the development of the principal types of vegetation in the region or regions considered, and what do these types of vegetation signify in terms of the crop-producing capabilities of the land on which they grow?

Similar studies have been made on the Great Plains (Shantz, 1911)[2] and in the Great Basin (Kearney, Briggs, Shantz, McLane, and Piemeisel, 1914)[3] and these studies have shown that the character and types of the natural plant cover indicate the potentialities for crop production of the soil and climate which produce them.

METHODS

The methods combine those usually employed by the systematist, the plant geographer, and the ecologist.

[1] Received for publication Feb. 28, 1924. The studies herein recorded have been carried on under the general direction of Dr. T. H. Kearney, Physiologist in Charge of Alkali and Drought Resistant Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. To him the authors are indebted for many suggestions in the preparation of the manuscript and for actual assistance in the field, especially in Coachella Valley, Calif., and Casa Grande, Ariz. Acknowledgment should also be made for the assistance of Homer Martin, Gardener, Alkali and Drought Resistant Plant Investigations, in the field work, and of Paul C. Standley of the United States National Herbarium, and Ivar Tidestrom, of the Bureau of Plant Industry, for the identification of the native plants listed in this paper.

[2] SHANTZ, H. L. NATURAL VEGETATION AS AN INDICATOR OF THE CAPABILITIES OF LAND FOR CROP PRODUCTION IN THE GREAT PLAINS AREA. U. S. Dept. Agr., Bur. Plant Indus. Bul. 201, 100 p., illus. 1911.

[3] KEARNEY, T. H., and others. INDICATOR SIGNIFICANCE OF VEGETATION IN TOOELE VALLEY, UTAH. Jour. Agr. Research. 1: 365-417, illus. 1914.

Herbarium material was collected whenever necessary. The plant communities have been studied in local areas and the classification applied over a wider area. The factor studies have included soil moisture determinations at the period of maximum soil moisture content and at the end of the growth period during the drought season. These soil moisture determinations have been interpreted by means of the wilting coefficient determinations on the same samples either made directly or by means of the moisture equivalent.

The soluble salt content of the soil has been determined by means of the electrical resistance method calibrated by means of gravimetrical determinations, and the composition of the soil salts has been determined in each region. For climatic and weather conditions we have relied on the United States Weather

FIG. 1.—Sketch map of the southwestern desert region, showing the location of the areas in which detailed studies of the vegetation have been made. The heavy black line shows the general area studied.

Bureau records, since detached determinations continuing throughout a year or two, or only a short period, give little reliable summation of the climatic conditions or indication of the normality or abnormality of the weather conditions. When cultivated crops were grown, direct correlation was made between vegetation and crop production.

LOCATION OF STUDIES

In this paper a study has been made of the vegetation of Coachella Valley, Calif., and of the Gila Valley in Arizona. Less detailed studies have been made at Casa Grande, Ariz.; Las Vegas and Searchlight, Nev.; Death Valley Junction, Saratoga Springs (Death Valley), Goffs, Needles, Hesperia, and the Mohave Desert, Calif.; and St. George, Utah (fig. 1). These studies were made during the years 1914, 1915, 1916, and 1917, the observations made during 1917 covering a more extended area. Similar studies have also been undertaken in New Mexico, the data from which will appear in a later publication.

COACHELLA VALLEY

PHYSIOGRAPHY

Coachella Valley, Calif. (fig. 1), lies between the San Bernardino Mountains on the north and east, and the San Jacinto and Santa Rosa Mountains on the south and west. The lower part of the valley bordering the Salton Sea has a very gradual slope. The upper part forms a plain that rises rapidly toward San Gorgonio Pass. The Coachella Valley is approximately 50 miles long, and, at the edge of the Salton Sea, 11 miles in width, the width gradually diminishing toward the north. The rise is quite abrupt on each side, making the uppe, zones of vegetation, creosote bush or creosote bush and bur-sage, very narrowr excepting the broad alluvial fans at the mouths of all the canyons opening into the valley. In places, as at Coral Reef, these zones practically disappear. The uniformity of the slope is broken north and west of Indio, Calif., at the highest water line by a series of large sand dunes, which separate the upper higher plain from the lower and more level part of the valley.

The lower part of Coachella Valley was at one time covered by a large body of fresh water, and later probably by the sea as an extension of the Gulf of California. Full discussions are given by Blake (1858)[4] and Free (1914)[5]. The area is shown on the map by the sealevel line, and includes approximately all that part of the valley below Indio. Evidences of the former presence of water are still to be seen in the countless numbers of shells strewn over the surface of the soil of this area and also in the deposits of tufa on the rocks as at Coral Reef.

SOILS

The soils of Coachella Valley are derived from the surrounding mountains. They are mainly of granitic origin, but some are derived from shale and sandstone.[6] The texture ranges from dune sand to clay loam. The two extreme types cover only small areas. The most prevalent types are a fine sandy loam and Fresno sand. The sandy loam occupies the lower part of the valley, while the Fresno sand forms the fans of alluvial soil at the mouth of canyons. The soils are generally light in color and porous. Even where the heavier soils occur on the surface there is usually a lower stratum of coarse sand or gravel. The lower part of the valley between the city of Coachella and the edge of the Salton Sea has heavy deposits of alkali. Here the water table rises high enough to keep the surface of the soil moist practically throughout the year. Alkali also occurs along the beds of some of the creeks and on the small areas of very heavy soil scattered in the upper part of the valley.

SALINITY

The salt content of the soils in Coachella Valley varies from barely appreciable amounts to thick white crusts on the surface. The variation in the salt content and in its composition is often great in very short distances, and complicates the interpretation of the plant growth. If lands of arrowweed, pickleweed, and saltgrass are selected so that the total salt content of the soils are about the same, the arrowweed land would be preferable because of the preponderance of sulphates rather than chlorids or carbonates as is apt to be the case in the pickleweed or saltgrass land. For instance, of two excessively saline locations about 100 feet apart in the dry bed of a creek, one was covered by a rank growth of arrow-

[4] BLAKE, W. P. REPORT OF A GEOLOGICAL RECONNAISSANCE IN CALIFORNIA. 370 p., illus. New York. 1858.

[5] FREE, E. E. SKETCH OF THE GEOLOGY AND SOILS OF THE CAHUILLA BASIN. *In* MacDougal, D. T., The Salton Sea, p. 21-33, illus. 1914. (Carnegie Inst. Wash. Pub. 193.)

[6] HOLMES, J. G. SOIL SURVEY OF THE INDIO AREA, CALIFORNIA. U. S. Dept. Agr. Bur. Soils, Adv. Sheets Field Oper. 1903, Indio soil map. 1904.

weed and the other by an equally good growth of pickleweed. The analyses of the salts of the arrowweed soil showed that over 63 per cent of the total salts were sulphates (sample 9, Table I) while the pickleweed soil showed a small amount of sulphates but over 57 per cent of the total salts as chlorids (sample 13, Table I). In another place where arrowweed was dying but saltgrass was thriving the fourth foot showed in the analyses (sample 8, Table I) over 26 per cent of the total salts to be bicarbonates and 6 per cent carbonates.

GILA VALLEY

PHYSIOGRAPHY

The part of Arizona studied lies between Chandler and the Gila River (fig. 1) and between Florence, Casa Grande, Maricopa, and the Gila River. Detailed studies were made at Casa Grande in the fall and at Chandler both in spring and in fall. The whole of this area is a broad valley plain that slopes gradually upward toward the east and south. On the west there is an abrupt upward slope toward the Salt River Mountains.

The center of the valley has been filled in to a great depth, leaving only the tops of the mountains rising above the valley floor. The material for this extensive filling was washed down from the Salt River mountains and others higher up on the drainage course.

SOILS

The soils of this area vary from the stony, partially disintegrated soils that lie at the bases of the mountains to the fine heavy soils, the "adobe," of the center of the valley. This change is usually gradual until the lower parts of the valley are reached, where there is often an abrupt change from the sandier types to the heavy clay loam. The nitrogen and humus content of practically all of the soils of the valley is low.[7]

TABLE I.—*Chemical composition of the salts of Coachella Valley soils, 1914 and 1915* [a]

[Crusts and surface soils were taken unless otherwise indicated. Results given in parts per 100,000 dry soil.]

Sample No.	Plant growth	Carbonates	Bicarbonates	Chlorids	Sulphates	Calcium	Magnesium	Sodium	Potassium	Total alkali
1	Cotton field		395	10,990	13,580	422	Trace.	13,380	Trace.	38,700
3	Cotton field		618	3,935	36,300	963	Trace.	18,800	Trace.	60,600
4	Washingtonia (palms)	1,065	717	2,980	13,500	379	Trace.	9,460	Trace	28,100
5	Allenrolfea (pickleweed)	Trace.	149	23,550	8,210	668	Trace.	18,720	Trace.	51,300
6	Dondia (seepweed) Isocoma	247	545	2,430	11,820	79	Trace.	7,580	Trace.	22,700
7	Dondia (seepweed)		233	12,700	7,100	38	Trace.	11,800	Trace.	31,900
8	Pluchea (arrowweed) dying, Distichlis (saltgrass), (fourth foot)	17	76	26	85	17	Trace.	80	Trace.	300
9	Pluchea (arrowweed)		160	564	10,830	230	Trace.	5,330	Trace.	17,100
10	Bare spot in field, crust		96	103	208	67	Trace.	127	Trace.	600
11	Bare spot in field, upper 6 inches		130	32	114	8	Trace.	116	Trace.	400
12	Date orchard		163	6,910	11,270	367	169	9,260	Trace.	28,200
13	Allenrolfea (pickleweed)		164	4,430	374	1,060	172	1,645	Trace.	7,800
14	Mesquite (young tree)		160	234	974	178	Trace.	468	Trace.	2,000
15	Bare spot in Pluchea (arrowweed) and Atriplex (saltbush)		229	8,380	5,450	6,100	392	6,725	Trace	21,800
16	Dondia (seepweed), crust	Trace.	140	20,220	23,690	286	Trace.	24,170	107	69,070
17	Dondia (seepweed), depth 1 foot		54	1,790	3,410	620	Trace.	2,054	84	8,000
18	Pluchea (arrowweed), Atriplex (saltbush), crust	5,030	7,940	3,340	37,760	30	40	26,883	248	82,210

[a] Analyses made by the Bureau of Soils, United States Department of Agriculture.

[7] MEANS, T. H. SOIL SURVEY IN SALT RIVER VALLEY, ARIZONA. U. S. Dept. Agr. Bur. Soils, Rpt. Field Oper. 1900: 287–332, illus. 1900.

SALINITY

The saline soils in the Gila Valley are confined largely to the areas where there is seepage or where the water table is high, as, for example, in the *Atriplex lentiformis* (Torr.) S. Wats. (saltbush) areas. Often considerable areas of saline land are found in the low places to which the salts have been washed by flood waters. Such are the bare flats and Dondia (seepweed) areas. Occasionally there is sufficient salt at the surface to form a crust especially in the *Atriplex lentiformis* areas. Of the salts composing the saline material, the chlorids are the most frequent and most abundant (Table II). The sulphates are next in importance. This

TABLE II.—*Chemical analyses of soils at Chandler, Arizona, 1915* [a, b]

[Results given in parts per 100,000]

Plant growth	Depth of sample	Sample number	Carbonates	Bicarbonates	Chlorids	Sulphates	Calcium	Magnesium	Sodium	Potassium	Nitrates	Total solids
Atriplex lentiformis (saltbush).	Composite sample first, second, third, fourth feet.	9	0	83	201	74	26	0	169	....	....	532
Atriplex lentiformis.	Composite sample first, second, third, fourth feet.	10	Trace.	145	90	74	0	0	149	....	....	432
Bare flat.....	Composite sample first, second, third, fourth feet.	11	0	48	910	240	195	35	450	....	40	1,960
Mesquite thicket (*Prosopis glandulosa*).	Composite sample first, second, third, fourth feet.	12	0	102	292	224	Trace.	0	338	....	....	956
Atriplex polycarpa (desert-sage).	Composite sample third and fourth feet.	13	0	86	360	117	37	0	279	....	....	892

[a] Analyses made by the Bureau of Soils, United States Department of Agriculture.

[b] See also: MEANS, T. H. SOIL SURVEY IN SALT RIVER VALLEY, ARIZONA. U. S. Dept. Agr. Bur. Soils, Rpt. Field Oper. 1900: 287-332, illus. 1900; and: ECKMANN, E. C., BALDWIN, M., and CARPENTER, E. J. SOIL SURVEY OF THE MIDDLE GILA VALLEY AREA, ARIZONA. U. S. Dept. Agr. Bur. Soils, Adv. Sheets Field Oper. 1917, 37 p., illus. 1920.

order is reversed in the Coachella Valley, where sulphates predominate. The bicarbonates, according to Table II, form a greater percentage of the salt content than in the Coachella Valley. This is also shown in an analysis by the Bureau of Soils (Table III).

The vegetation and soil conditions in the vicinity of Casa Grande, Ariz., were also studied. The salts of the soils at Casa Grande (Table IV) show more sulphates than chlorids, and in this respect resemble the salts of Coachella Valley.

VEGETATION

COACHELLA VALLEY

The plant communities in Coachella Valley are usually sharply differentiated, particularly those occupying the lower areas where the soil is comparatively well supplied with moisture for growth and contains large quantities of alkali salts. The uplands which are occupied by alkali-avoiding and more drought-evading species, are characterized by a more mixed vegetation. No attempt is made to distinguish the smaller plant communities, which are not as marked in the vegetation of the shrubby desert formations as they are in the grass formations. The associations, however, are much more uniform in composition and are often dominated by a single species.

TABLE III.—*Chemical analyses of alkali salts of Tempe, Arizona, sheet* [a]

Constituent	4470 Sec. 9, T. 1 N., R. 3 E. (0–12 inches)	4469 Sec. 27, T. 1 N., R. 4 E. (0–12 inches)	4541 Sec. 22, T. 1 N., R. 3 E. (crust)	4468 Sec. 3, T. 1 S., R. 4 E. (crust)	4472 Sec. 3, T. 1 S., R. 4 E. (0–12 inches)	4465 Sec. 22, T. 1 S., R. 4 E. (crust)	4466 2 miles south Kyrene (crust)
Ca	13.32	0.31	6.37	0.47	0.65	6.73	4.38
Mg	4.44	.31	4.20	.62	.57	4.03	1.34
Na	14.93	34.90	23.03	30.99	31.55	22.04	29.47
K	2.88	2.50	.00	6.40	5.01	2.12	1.55
SO_4	5.34	12.16	26.40	9.60	9.76	.91	16.78
Cl	56.93	46.38	39.55	42.01	41.73	61.48	44.83
CO_3		.18	.10	2.34	1.45		
HCO_3	2.16	3.28		7.57	9.28	0.70	1.62
$CaSO_4$	7.56	1.07	22.31	1.56	2.18	1.28	14.86
$MgSO_4$		1.52	13.34	3.04	2.74		6.13
$MgCl_2$	17.40		5.94			15.81	
KCl	5.46	4.74	0.00	12.18	9.53	4.03	3.13
NaCl	35.98	72.84	57.97	59.72	61.35	60.33	71.53
Na_2CO_3		.31	1.44	4.14	2.50		
$NaHCO_3$	2.94	4.47		10.38	12.76	.96	2.27
Na_2SO_4		15.05		8.98	8.96		2.06
$CaCl_2$	30.66					17.59	
Per cent soluble salts	3.33	4.47	7.24	2.56	2.48	8.58	5.80

[a] MEANS, T. H. SOIL SURVEY IN SALT RIVER VALLEY, ARIZONA. U. S. Dept. Agr. Bur. Soils, Rpt. Field Oper. 1900: 287–332, illus. 1900.

TABLE IV.—*Chemical analyses of composite samples of second, third, and fourth feet of soil at Casa Grande, Arizona, 1915* [a]

[Results given in parts per 100,000]

Plant growth	Sample No.	Carbonates	Bicarbonates	Chlorids	Sulphates	Calcium	Magnesium	Sodium	Potassium	Nitrates	Total solids by evaporation
Poor Covillea and *Atriplex linearis*	4	0	53	41	87	42	Trace.	50	16	Trace.	290
Atriplex polycarpa	14	0	55	54	166	10	Trace.	125	Trace.	Trace.	410
Atriplex fasiculata	5	0	36	200	249	16	Trace.	245	12	Trace.	760
Atriplex fasiculata	11	31	74	108	353	10	Trace.	238	Trace.	Trace.	810
Atriplex polycarpa, *Atriplex linearis* (in Opuntia belt)	9	0	64	88	416	18	Trace.	255	16	Trace.	860
Atriplex linearis	15	6	68	122	568	41	Trace.	339	Trace.	Trace.	1,140
Dondia intermedia	10	106	102	114	348	10	Trace.	388	10	Trace.	1,170

[a] Analyses made in Dr. E. C. Shorey's laboratory, Bureau of Soils, United States Department of Agriculture.

The plant communities in Coachella Valley are as follows:

Plant communities	*Dominant species*
Associations—	
Yucca and cactus	*Yucca mohavensis* Sarg. (yucca).
	Ferocactus acanthodes (Lemaire) Britton & Rose (cactus).
	Opuntia bigelovii Engelm. (cactus).
	Franseria dumosa A. Gray (bur-sage).
Creosote bush and bur-sage	*Covillea glutinosa* (Engelm.) Rydb. (creosote bush) *Franseria dumosa* A. Gray (bur-sage).
Creosote bush	*Covillea glutinosa* (Engelm.) Rydb. (creosote bush).

Associations—Continued.

Desert-sage	*Atriplex polycarpa* (Torr.) S. Wats. (desert-sage).
Seepweed	*Dondia torreyana* (S. Wats.) Standl. (seepweed).
Saltgrass	*Distichlis spicata* (L.) Greene (saltgrass).
Pickleweed	*Allenrolfea occidentalis* (S. Wats.) Kuntze (pickleweed).

Minor communities—

Mesquite and chamiso	*Atriplex canescens* (Pursh) Nutt. (chamiso). *Prosopis glandulosa* (Torr.) (mesquite).
Washington palm	*Washingtonia filifera* Wendl. (Washington palm).
Arrowweed and saltbush	*Pluchea sericea* (Nutt.) Coville (arrowweed). *Atriplex lentiformis* (Torr.) S. Wats. (saltbush).

DISTRIBUTION OF THE TYPES OF VEGETATION

The map (fig. 2) shows the distribution and the respective areas of the vegetation types of Coachella Valley. If the types of vegetation of the valley are divided into two groups, one including the types above and the other those below sealevel, the first group would include (*a*) Yucca and cactus; (*b*) creosote bush; (*c*) creosote bush and bur-sage; (*d*) mesquite and chamiso; and (*e*) Washingtonia palm, as the types above sealevel. The second group: (*f*) desert-sage; (*g*) arrowweed and saltbush; (*h*) seepweed; (*i*) saltgrass; and (*j*) pickleweed, the types below sealevel.

The Yucca and cactus area is the type of vegetation highest above sealevel. It covers the lower hills on the west side of the valley and broadens out above Whitewater over the more level but high lands.

Bordering on the lower margin is the area dominated by creosote bush. In places bur-sage is so mixed with creosote bush that it is of equal importance. The lands covered by this type are the fans at the mouths of canyons and the higher bench lands skirting the hills on each side and a broad level area across the valley between Whitewater and Palm Springs.

The mesquite and chamiso area embraces the sand dunes and sandy areas. These sandy areas occur west and southwest of Indio and also northwest beyond Indian Wells, and are the result of the winds blowing down San Gorgonio Pass. These winds pick up material in blowing over the higher desert lands, become laden with sand and dust and drop their burden wherever the force of the wind is slackened.

The change of the slope from the fans covered by the creosote bush to the adjoining valley floor, covered by the desert-sage, is very abrupt and sets off the two associations very definitely, as regards soil texture, soil moisture, and salt content.

While most of the lands covered by the desert-sage are below the sealevel line, some are slightly above it. They form an almost continuous belt along the sides of and at Indio, across the valley except where the sandhills or the cultivated areas break in on them.

Just below the desert-sage belt, and considerably below sealevel, are the narrow irregular strips of saline land covered with Dondia (seepweed). Occupying the center of the valley is the land covered with arrowweed, saltbush, or pickleweed. This is the heaviest, wettest, and most saline type of land in the valley. Small meadows formed by saltgrass are scattered within the last two types.

GILA VALLEY

The two most important types of vegetation, namely, the creosote bush and desert-sage associations, are the same as and occupy similar positions to those in the Coachella Valley. The creosote bush covers the fans and higher benches

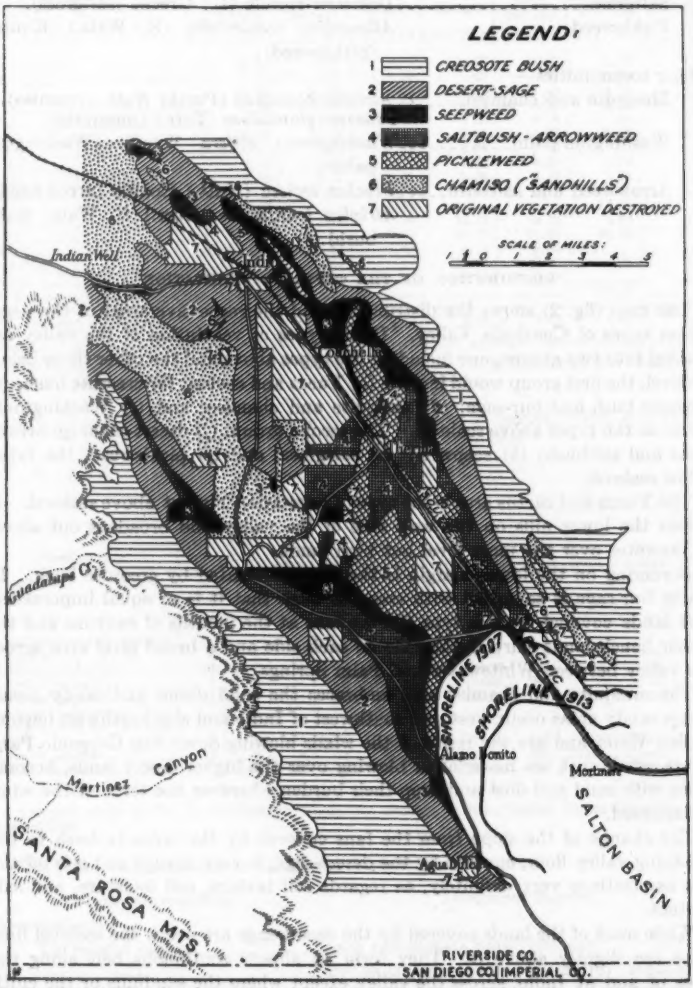

FIG. 2.—Map showing the plant communities in Coachella Valley. The map is carried only to the base of the foothills, above which there is a very irregular area of yucca and cactus. Coachella Valley, Calif., 1915.

next to the mountains and the desert-sage occupies the adjoining lower lands having a soil of finer texture with the particles more weathered. The change of slope is much more gradual than in Coachella Valley, and hence the changes in soil conditions, texture, moisture, and salt content are less abrupt. There are

many alternations of the creosote bush and desert-sage areas and the two mix to a large extent (fig. 3).

The following are the principal plant communities in the Gila Valley:

Plant communities	*Dominant species*
Associations—	
Giant cactus and paloverde	*Carnegiea gigantea* (Engelm.) Britton & Rose (giant cactus).
	Cercidium torreyanum (S. Wats.) Sarg. (paloverde).
Creosote bush and bur-sage	*Covillea glutinosa* (Engelm.) Rydb. (creosote bush).
	Franseria dumosa A. Gray (bur-sage).
Creosote bush	*Covillea glutinosa* (Engelm.) Rydb. (creosote bush).
Desert-sage	*Atriplex polycarpa* (Torr.) S. Wats. (desert-sage).
Narrowleaf saltbush	*Atriplex linearis* S. Wats. (narrowleaf saltbush).
Seepweed	*Dondia intermedia* (S. Wats.) Heller (seepweed).
Saltgrass	*Distichlis spicata* (L.) Greene (salt grass).
Minor communities—	
Chamiso	*Atriplex canescens* (Pursh) Nutt. (chamiso).
Atriplex fasciculata	*Atriplex fasciculata* S. Wats.
Saltbush	*Atriplex lentiformis* (Torr.) S. Wats. (saltbush).
Mesquite thicket	*Prosopis glandulosa* Torr. (mesquite).

The chamiso (*Atriplex canescens* (Pursh) Nutt.) covers the sandy ridges and knolls occurring in the desert-sage areas. Towards the lower parts of the valley there is a gradual change from pure desert-sage to that mixed with narrowleaf saltbush or seepweed. Still lower these shrubs mix with the mesquite. The shrubs and seepweed grow on low hummocks, composed of a light soil piled by the wind in the open spaces between the mesquite trees. In low places where there is subirrigation the mesquite becomes a thicket and excludes the other shrubs.

The lands along the rivers and creeks and the abandoned "seepland," where the water table is high, are covered with saltbush (*Atriplex lentiformis* (Torr.) S. Wats.).

In the vicinity of Casa Grande the vegetation is very similar to that in the Gila Valley. It differs most conspicuously from that in Coachella Valley in the absence of the large areas of pickleweed and arrowweed and saltbush which cover the wet saline lands. Near Casa Grande there are dry saline lands covered either with seepweed, narrowleaf saltbush or an annual Atriplex (*A. fasciculata* S. Wats.).

The creosote bush and desert-sage are, by far, the most important types of vegetation in this section. While they occupy the same relative position as in the Coachella and Gila Valleys the lines between them are much more obscure than in the former, and slightly more so than in the latter locality. This is due to the very gentle slope of the land, which causes the soil conditions, texture, moisture, and salinity to change very gradually. These two types of vegetation alternate frequently and near the lines of contact mix to a considerable extent.

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Narrowleaf saltbush covers small tracts in the desert sage area especially where the soil is shallow. Seepweed and *Atriplex fasciculata* S. Wats. cover low flat places where the water collects after a rain and the salt content is high.

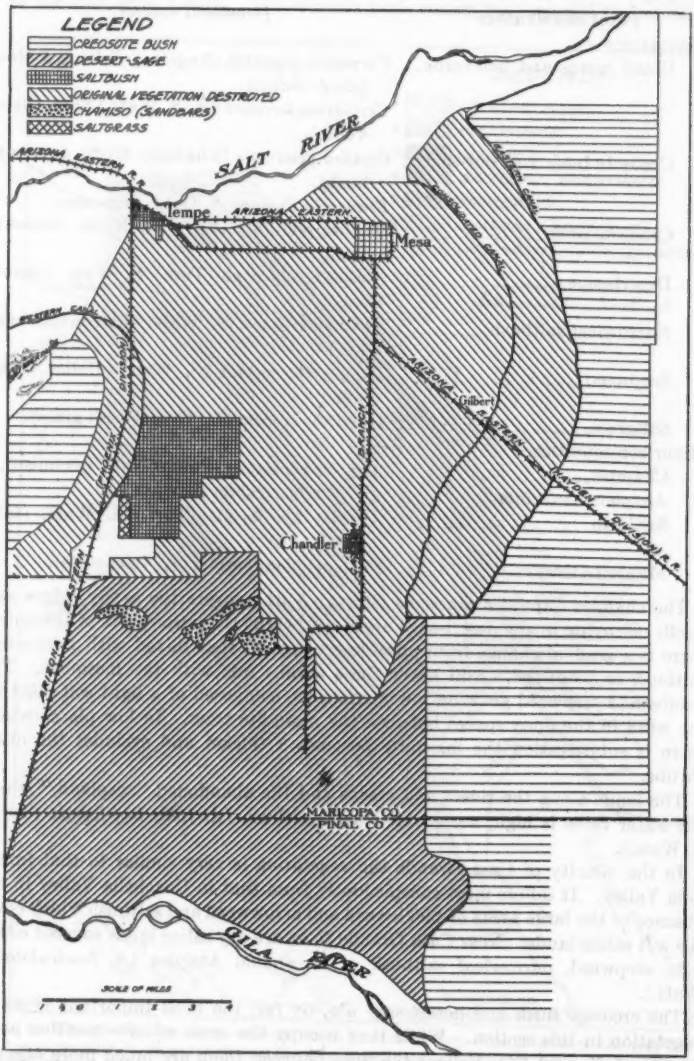

FIG. 3.—Map showing the distribution of the important plant communities in a small area in the Gila Valley. This map gives an idea of the relative importance of the different types. Gila Valley, Ariz., 1915.

DETAILED DESCRIPTION OF PLANT COMMUNITIES

Detailed description of the plant communities together with discussions of the soil conditions found in typical areas of those communities are given in the following pages.

In so far as possible the common names of plants are used throughout the text. However, in the discussion of each association under the paragraph heading, "Botanical Composition," a list of the plants noted is given with the botanical names in full. The following list gives the common names used in the text, together with the botanical names:

Annual fescue	*Festuca octoflora* Walt.
Arrowweed	*Pluchea sericea* (Nutt.) Coville.
Bur-sage	*Franseria dumosa* A. Gray.
Chamiso	*Atriplex canescens* (Pursh) Nutt.
Creosote bush	*Covillea glutinosa* (Engelm.) Rydb.
Desert plantain	*Plantago erecta* Morris.
Desert-sage	*Atriplex polycarpa* (Torr.) S. Wats.
Desert-willow	*Chilopsis linearis* (Cav.) Sweet.
Giant cactus	*Carnegiea gigantea* (Engelm.) Britton & Rose.
Greasewood	*Sarcobatus vermiculatus* (Hook.) Torr.
Mesquite	*Prosopis glandulosa* Torr.
Narrowleaf saltbush	*Atriplex linearis* S. Wats.
Paloverde	*Cercidium torreyanum* (S. Wats.) Sarg.
Pickleweed	*Allenrolfea occidentalis* (S. Wats.) Kuntze.
Sagebrush	*Artemisia tridentata* Nutt.
Saltbush	*Atriplex lentiformis* (Torr.) S. Wats.
Saltgrass	*Distichlis spicata* (L.) Greene.
Seepweed	*Dondia torreyana* (S. Wats.) Standl. (Coachella Valley).
Do	*Dondia intermedia* (S. Wats.) Heller (Gila Valley).
Shadscale	*Atriplex confertifolia* (Torr.) S. Wats.
Washington palm	*Washingtonia filifera* Wendl.
Yellow pine	*Pinus ponderosa* Laws.

YUCCA AND CACTUS ASSOCIATION

The lower mountains surrounding the Coachella Valley are covered only with low shrubby desert growth. On the north side of the valley the hills are of clay or silt texture and weather down rapidly to form bad lands (Pl. 1, A). The vegetation on this loose cracked clay soil probably represents only successional phases, and is very sparse. It consists of the following species:

Atriplex hymenelytra (Torr.) S. Wats.
Plantago erecta Morris.
Calyptridium monandrum Nutt.
Chamaesyce melanadenia (Torr.) Millsp.
Eriogonum thomasii Torr.
Monoptilon bellioides (A. Gray) Hall.
Lotus strigosus (Nutt.) Greene.
Cryptanthe sp.

At a short distance the low mountains and hills appear entirely bare, but except where bad lands occur they are characterized by the Yucca and cactus association (Pl. 1, B). The following are the more important species:

Yucca mohavensis Sarg.
Ferocactus acanthodes (Lemaire) Britton & Rose.
Opuntia bigelovii Engelm.
Encelia farinosa A. Gray.
Franseria dumosa A. Gray.
Ephedra californica S. Wats.
Eriogonum fasciculatum Benth.
Krameria grayi Rose & Painter.
Antirrhinum coulterianum Benth.
Eriodictyon tomentosum Benth.
Fouquieria splendens Englem.

Plants common along washes (Pl. 2, A) in Coachella Valley may be listed as a modification of this same association. The more important plants are:

Parosela arborescens (Torr.) Heller.
Chilopsis linearis (Cav.) Sweet.
Hymenoclea salsola Torr. & Gray.
Cercidium torreyanum (S. Wats.) Sarg.
Parosela schottii (Torr.) Heller.
Asclepias subulata Decne.
Bebbia juncea aspera Greene.
Olneya tesota A. Gray.
Petalonyx thurberi A. Gray.
Psathyrotes ramosissima (Torr.) Gray.
Eriogonum thomasii Torr.
Beloperone californica Benth.
Lupinus sp.
Phacelia sp.

GIANT CACTUS AND PALOVERDE ASSOCIATION

The low hills surrounding the Gila Valley and the residual soils, which are rough and stony, are characterized by the giant cactus and paloverde type of vegetation (Pl. 2, B). This is similar in general character to the Yucca and cactus type in Coachella Valley, though here the appearance is much more striking due, on the one hand, to the larger areas, a result of the gradual slope, and, on the other hand, to the giant cactus, *Carnegiea gigantea* (Engelm.) Britton & Rose, which stands high above all other plants. The higher rainfall in this region produces a much more luxuriant type of desert growth, and it is doubtful if any type of vegetation in the United States presents more interesting plants (Pl. 3, A).

This association is well developed in the region about Chandler, Ariz. The following list gives a good idea of the botanical composition:

PERENNIAL SPECIES

Common or Frequent

Carnegiea gigantea (Engelm.) Britton & Rose.
Cercidium torreyanum (S. Wats.) Sarg.
Opuntia bigelovii Engelm.
Ferocactus wislizeni (Engelm.) Britton & Rose.
Fouquieria splendens Engelm.
Encelia farinosa A. Gray.
Franseria dumosa A. Gray.
Covillea glutinosa (Engelm.) Rydb.
Franseria deltoides Torr.
Eriogonum fasciculatum Benth.
Olneya tesota A. Gray.

Less Frequent or Rare

Simmondsia californica Nutt.
Sphaeralcea coulteri A. Gray.

ANNUAL AND BIENNIAL SPECIES

Common or Frequent

Plantago fastigiata Morris.
Festuca octoflora Walt.
Thelypodium lasiophyllum (Hook. & Arn.) Greene.
Amsinckia intermedia Fisch. & Mey.
Pectocarya penicillata (Hook. & Arn.) A. DC.
Tillaestrum aquaticum (L.) Britt.
Phacelia sp.
Lepidium lasiocarpum Nutt.
Conanthus demissus (A. Gray) Heller.
Baeria aristata (Nutt.) Coville.
Cryptanthe sp.

Less Frequent or Rare

Aristida adscensionis L.
Brodiaea capitata pauciflora Torr.
Baeria chrysostoma Fisch. & Mey.
Calandrinia caulescens H. B. K.
Chaenactis carphoclinia A. Gray.
Chaenactis stevioides Hook. & Arn.
Chamaesyce polycarpa (Benth.) Millsp.
Cryptanthe pterocarpa (Torr.) Greene.
Monoptilon bellioides (A. Gray) Hall.
Gilia inconspicua (J. E. Smith) Dougl.
Lesquerella gordoni sessilis S. Wats.
Linanthus dactylophyllus (Torr.) Rydb.
Lotus sp.
Lotus subpinnatus Lag. (?)
Lotus strigosus (Nutt.) Greene.
Lupinus concinnus Agardb. (?)
Mentzelia albicaulis Dougl.
Orthocarpus purpurascens Benth.
Pachylophus (?)
Phacelia crenulata Torr.
Plantago erecta Morris.
Salvia columbariae Benth.
Silene antirrhina L.
Sphaerostigma decorticans (Hook. & Arn.) Small.

The soil conditions of the giant cactus and paloverde association at Chandler, Ariz., in 1915 are shown in Table V.

TABLE V.—*Soil conditions in giant cactus and paloverde association at Chandler, Ariz., 1915* [a]

Item	Depth of soil	Date of collection				
		March 28		Average	October 5	
		Sample [b] No. 23	Sample [c] No. 25		Sample No. 23	Sample No. 25
	Feet					
Moisture equivalent	1	9.1	17.8	13.4	.....	17.6
	2	8.3	22.2	15.3	.....	21.5
	3	7.1	23.6	15.4	.....	26.5
	4	6.9	19.6	13.2	.....	19.1
Wilting coefficient	1	5.0	9.7	7.3	.....	9.6
	2	4.5	12.0	8.3	.....	11.7
	3	3.9	12.8	8.4	.....	14.4
	4	3.8	10.6	7.2	.....	10.4
Moisture content above or below wilting coefficient.	1	−2.1	+0.4	−0.9	.....	−3.0
	2	−0.8	+5.8	+2.5	.....	−3.7
	3	−0.6	+5.9	+2.7	.....	−6.6
	4	−0.2	+6.7	+3.3	.....	+0.5
Salt content	1	.....	.07	.....	.....	.11
	2	.....	.10	.....	.....	.09
	3	.....	.17	.....	.....	.14
	4	.....	.34	.....	.....	.26

[a] All data in this table are stated in percentages of the dry weight of the soil.
[b] Taken in a typical area in the upper part of this association in a very stony soil near the hills.
[c] Taken in the lower part of this association mixed with desert-sage.

CREOSOTE BUSH ASSOCIATION

TOPOGRAPHICAL RELATIONS

In the southwestern desert region the creosote bush association is the most important type of vegetation. It covers an area that includes the Mohave desert, Coachella Valley, Imperial Valley, Salt River Valley, Gila Valley, Death Valley, and most of the southern portion of New Mexico, Arizona, and the Transpecos region of western Texas.

The creosote bush areas cover the high benches, the fans at the mouth of canyons, and strips of land lying at the base of the hills. Where the slope at

the base of the hills is gentle, as in the Gila Valley, this strip of creosote bush may be several miles in width. In Coachella Valley where the slope from the hills to the valley floor is very abrupt, the creosote bush may be excluded, as at Coral Reef. In addition to the areas mentioned above, the creosote bush covers slight rises in the valley floor especially where these higher areas are composed of a light porous soil. Due to the fact that such a large portion of the creosote bush areas lies above the highest irrigation canals, these areas are not cultivated to the extent that the desert-sage lands are.

With respect to the other plant associations, the cresote bush association lies just above the desert-sage and below the giant cactus and paloverde or Yucca and cactus associations.

BOTANICAL COMPOSITION

Typical areas of creosote bush (*Covillea glutinosa* (Engelm.) Rydb.) contain practically no other shrubs (figs. 4 and 5). Most of the creosote bush land is

FIG. 4.—A 10-meter quadrat in a typical area in the creosote bush association. *C* indicates the individual plants of creosote bush, *Covillea glutinosa* (Engelm.) Rydb., the only shrub present. The important annuals and small perennials were *Plantago erecta* Morris, *Thelypodium lasiophyllum* (Hook. & Arn) Greene, *Pectocarya penicillata* (Hook. & Arn.) A. DC., *Eremalche exilis* (A. Gray) Greene, *Abronia villosa* S. Wats., *Chaenactis* sp., *Chylisma cardiophylla* (Torr.) Small, *Cryptanthe intermedia* (A. Gray) Greene and *Chylisma scapoidea* (Nutt.) Small. Mapped March 2, 1915, at Indian Wells, Calif.

divided by washes, the plant growth of which is very different. These washes occur very frequently on the higher slopes so that the uniformity of the creosote bush areas is interrupted. At the lower edge of the creosote bush areas where the slope is gentle these washes are much wider in extent but not so frequent, and the creosote bush areas are much more uniform. The plants occurring along the washes are merely a part of the association lying just above the creosote bush association. These plants are not included in the lists for the creosote bush areas, but are listed under the giant cactus and paloverde or Yucca and cactus associations.

The perennial species of plants recorded as occurring in the creosote bush areas in Coachella and Gila Valleys are given in the following lists:

PERENNIAL SPECIES OF CREOSOTE BUSH ASSOCIATION IN COACHELLA VALLEY

Common or Frequent

Covillea glutinosa (Engelm.) Rydb.
Franseria dumosa A. Gray.
Lotus strigosus (Nutt.) Greene.
Abronia villosa S. Wats.
Coldenia nuttallii Hook.
Gerasea eriocephala (A. Gray) Blake.

Less Frequent or Rare

Antirrhinum coulterianum Benth.
Croton californicus Muell. Arg.
Eriogonum fasciculatum Benth.
Gilia densifolia Benth.
Hesperonia retrorsa (Heller) Standl.
Hoffmanseggia microphylla Torr.
Isomeris arborea Nutt.
Krameria grayi Rose & Painter.
Nicotiana attenuata Torr.
Oryzopsis hymenoides (Roem. & Schult.) Ricker.
Hilaria rigida (Thurb.) Benth.
Aplopappus linearifolius interior (Coville) Jones.
Aplopappus linearifolius DC.
Stillingia linearifolia (Torr.) Small.

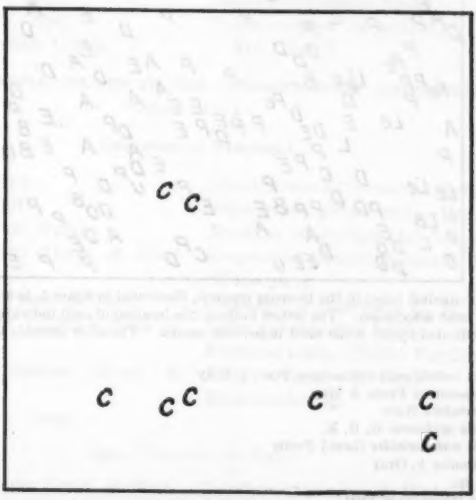

FIG. 5.—A 10-meter quadrat in a representative area of the creosote bush association, showing the individual plants of *Covillea glutinosa* (Engelm.) Rydb. indicated by *C*, the only shrubby species present. For a detail of the annual flora see figure 6. Mapped March 29, 1915, Chandler, Ariz.

PERENNIAL SPECIES OF CREOSOTE BUSH ASSOCIATION IN GILA VALLEY

Common or Frequent

Covillea glutinosa (Engelm.) Rydb.
Franseria dumosa A. Gray.
Sphaeralcea sp.
Astragalus nuttallianus trichocarpus Torr. & Gray.

Less Freuqent or Rare

Astragalus sp.
Lycium gracilipes A. Gray.
Sphaeralcea coulteri A. Gray?
Triodia pulchella H. B. K.
Zizyphus lycioides canescens A. Gray.

There are a large number of annuals found in the typical creosote bush areas (fig. 6.)

Of these the desert plantain (*Plantago erecta* Morris) is the most abundant and has the widest distribution. It occurs as the most important annual both in the Coachella and Gila Valleys. Annual fescue (*Festuca octoflora* Walt.) is the next

most important annual in creosote bush areas in the Gila Valley, and *Cryptanthe intermedia* (A. Gray) Greene in the Coachella Valley. Plants of *Amsinckia menziesii* (Lehm.) Nels. & Macbr. and *Thelypodium lasiophyllum* (Hook. & Arn.) Greene, tall annuals that grow clustered around the base of the creosote bush, are common to both the valleys. The other annuals or biennials recorded for the Gila and Coachella Valleys are given below:

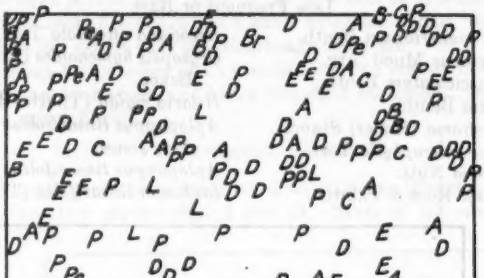

FIG. 6.—A 1-meter quadrat taken in the 10-meter quadrat, illustrated in figure 5, to show the annual flora in the creosote bush association. The letters indicate the location of each individual plant. *Plantago erecta* Morris indicated by (P) is the most important annual. The other annuals and small perennials are as follows:

A= *Astragalus nuttallianus trichocarpus* Torr. & Gray
B= *Baeria chrysostoma* Fisch. & Mey.
Br= *Festuca octoflora* Walt.
C= *Calandrinia caulescens* H. B. K.
D= *Matricaria matricarioides* (Less.) Porter
E= *Filago arizonica* A. Gray
L= *Allocarya* sp.
La= *Lepidium lasiocarpum* Nutt.
Pe= *Pectocarya penicillata* (Hook & Arn.) A. DC.
U= *Daucus pusillus* Michx.
Mapped March 29, 1915, Chandler, Ariz.

ANNUAL AND BIENNIAL SPECIES OF THE CREOSOTE BUSH ASSOCIATION IN THE COACHELLA VALLEY

Common or Frequent

Plantago erecta Morris.
Cryptanthe intermedia (A. Gray) Greene.
Baeria chrysostoma Fisch. & Mey.
Sphaerostigma veitchianum (Hook.) Small.
Chylisma scapoidea (Nutt.) Small.
Pectocarya penicillata (Hook. & Arn.) A. DC.
Thelypodium lasiophyllum (Hook. & Arn.) Greene.
Chylisma cardiophylla (Torr.) Small.
Chamaesyce melanadenia (Torr.) Millsp.
Lupinus concinnus Agardh.
Lepidium lasiocarpum Nutt.
Conanthus demissus (A. Gray) Heller.
Eriogonum thomasii Torr.
Calyptridium monandrum Nutt.
Amsinckia menziesii (Lehm.) Nels. & Macbr.
Phacelia crenulata Torr.
Eremalche exilis (A. Gray) Greene.
Mentzelia albicaulis Dougl.
Dithyrea californica Harv.

Less Frequent or Rare

Achyronychia cooperi Torr. & Gray.
Anogra californica (S. Wats.) Small.
Aristida adscensionis L.
Chaenactis sp.
Chaenactis fremontii A. Gray.
Chaenactis carphoclinia A. Gray.
Chorizanthe corrugata (Torr.) Torr. & Gray.
Chorizanthe rigida (Torr.) Torr. & Gray.
Coreopsis douglasii (DC.) H. M. Hall.
Cryptanthe muriculata (A. Gray) Greene.
Eriogonum thurberi Torr.
Eriogonum inflatum Torr.
Erodium texanum A. Gray.
Eschscholtzia californica Cham.
Euphorbia sp.
Hordeum murinum L.
Layia glandulosa (Hook.) Hook. & Arn.
Linanthus lemmoni (A. Gray) Greene.
Lupinus sp.
Mohavia viscida A. Gray.
Monoptilon bellioides (A. Gray) Hall.
Nemoseris californica (Nutt.) Greene.
Palafoxia linearis Lag.
Parosela mollis (Benth.) Heller.
Phacelia sp.
Phacelia distans Benth.
Plantago fastigiata Morris.
Salvia columbariae Benth.
Sphaerostigma decorticans (Hook. & Arn.) Small.

ANNUAL AND BIENNIAL SPECIES IN THE CREOSOTE BUSH ASSOCIATION IN THE GILA VALLEY

Common or Frequent

Plantago erecta Morris.
Festuca octoflora Walt.
Lepidium lasiocarpum Nutt.
Peclocarya penicillata (Hook. & Arn.) A. DC.
Baeria chrysostoma Fisch. & Mey.
Amsinckia menziesii (Lehm.) Nels. & Macbr.
Thelypodium lasiophyllum (Hook. & Arn.) Greene.
Eriodium texanum A. Gray.
Matricaria matricarioides (Less.) Porter.
Orthocarpus purpurascens Benth.
Erodium cicutarium (L.) L'Hér.
Lesquerella gordoni sessilis S. Wats.
Allocarya sp.
Calandrinia caulescens H. B. K.
Lotus subpinnatus Lag?
Baeria aristata (Nutt.) Coville.
Filago arizonica A. Gray?
Eschscholtzia sp.

Less Frequent or Rare

Bowlesia septentrionalis Coult. & Rose.
Chylisma scapoidea (Nutt.) Small.
Conanthus demissus (A. Gray) Heller.
Daucus pusillus Michx.?
Draba cuneifolia Nutt.
Evax multicaulis D. C.
Gaillardia arizonica A. Gray.
Eschscholtzia californica Cham.
Linaria canadensis (L.) Dumort.
Lupinus sp.
Lupinus arizonicus S. Wats.
Monolepis nuttalliana (Schutt.) Greene.
Pachylophus?
Plagiobothrys arizonicus (A. Gray) Greene.
Plantago fastigiata Morris.
Poa bigelovii Vasey & Scribn.
Salvia columbariae Benth.
Silene antirrhina L.

APPEARANCE

Normally the creosote bush is a dark brownish-green shrub about 5 feet high (Pl. 3, B and 4, A.) It divides at the surface of the ground into several main branches, which branch again sparingly, giving the appearance of an open bush. The dark brownish-green color is due to the thick resin-covered leaves, which are in pairs and occur most abundantly on the young twigs. In the spring these twigs bear numerous small bright yellow flowers. Pure areas of creosote bush

present a very uniform appearance. The bushes are regularly but widely spaced with the intervening ground covered with annuals. Where there is a good growth of the creosote bush covering large areas the plants are from 5 to 7 feet high, although scattered plants in very favorable locations attain a height of 10 feet or even more. A poor growth consists of low scraggy, open plants, 2 to 5 feet high, with a few branches sparsely covered with leaves. In the fall, when the moisture supply has been exhausted this growth is decidedly brown, while the good growth where moisture is still available shows dark green. The dark brownish-green of this association contrasts sharply with the light gray of the desert-sage association.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

The soil in this area in Coachella Valley is light and porous and is composed of coarse unweathered particles of rock. The moisture equivalents (Table VI) show that the moisture-holding capacity is low. The penetration of water into this soil is very rapid and much deeper than in the desert-sage. In March there is available water to a depth of 4 feet, while late in summer there is none at that depth. Creosote bush is never found on soils where the water table is high.

TABLE VI.—*Comparisons of spring and fall soil conditions at the same stations in typical creosote bush areas. Indio, Calif., 1915*[a]

Item	Depth of soil	Date of collection					Average	Date of collection					Average
		Mar. 2, sample No. 6	Mar. 2, sample No. 7	Mar. 2, sample No. 8	Mar 3, sample No. 9	Mar. 3, sample No. 10		Sept. 21, sample No. 6	Sept. 21, sample No. 7	Sept. 21, sample No. 8	Sept. 24, sample No. 9	Sept. 24, sample No. 10	
Moisture equivalent	*Feet*												
	1	3.8	3.4	4.2	2.3	2.6	3.3	3.7	6.5	3.6	1.9	2.8	3.7
	2	3.4	2.6	5.9	3.0	2.7	3.5	3.9	8.0	4.3	3.3	3.1	4.5
	3	3.4	2.1	2.9	3.0	2.8	2.8	4.0	5.4	3.6	3.5	3.0	3.9
	4	2.8	3.1	2.8	2.1	2.7	2.7	3.6	6.5	3.2	2.9	4.1	4.1
Wilting coefficient	1	2.0	1.8	2.3	1.3	1.4	1.8	2.1	3.5	2.0	1.0	1.5	2.0
	2	1.8	1.4	3.2	1.6	1.5	1.9	2.1	4.4	2.3	1.8	1.7	2.5
	3	1.8	1.1	1.6	1.6	1.5	1.5	2.0	2.9	2.0	1.9	1.6	2.1
	4	1.5	1.7	1.5	1.1	1.5	1.5	2.0	3.5	1.7	1.6	2.2	2.1
Moisture content above or below wilting coefficient	1	+1.4	+3.0	+2.8	+0.9	+1.9	+3.0	−1.1	−1.7	−1.0	−0.8	−1.2	−1.2
	2	+3.0	+3.8	+3.0	+4.4	+2.9	+4.4	−0.9	−3.2	−1.3	−1.4	−1.4	−1.6
	3	+4.3	+5.0	+3.5	+6.9	+2.4	+4.4	−1.6	−1.8	−1.3	−1.3	−1.1	−1.2
	4	+2.6	+0.9	+1.9	+3.3	+2.8	+2.3	−1.4	−1.7	−0.7	−1.2	−1.6	−1.3
Salt content[b]	1	<.01	<.01	<.01	<.01	<.01	<.01	.01	<.01	<.01	.02	<.01	.01
	2	<.01	<.01	<.01	<.01	<.01	<.01	.01	<.01	<.01	.01	<.01	.01
	3	<.01	<.01	.02	<.01	<.01	.01	.01	<.01	<.01	.01	<.01	.01
	4	.01	<.01	.02	.02	<.01	.01	.01	.02	<.01	<.01	<.01	.01

[a] All data in this table are stated in percentages of the dry weight of the soil.
[b] Electrical resistance readings over 3,000 ohms indicated less than (<) 0.01 per cent.

In considering soil moisture conditions in the different associations reference should be made to figure 7 which shows the daily rainfall for three stations in Coachella Valley. It is evident at a glance that no soil moisture had been added during the summer of 1915 and that whatever growth the plants had made was due to the soil moisture present at the beginning of the growing season in March (Table VI).

A comparison of the soil of the creosote bush land in Gila Valley with that in Coachella Valley shows (Tables VI and VII) the texture of the former to be much finer, with the moisture equivalents two or three times as high, which increases the

moisture-holding capacity of the soil but reduces the penetration. There was very little available water in the first foot when the samples were taken in the spring (March 15–27), and the amount was less in the second, third, and fourth foot than that found in Coachella Valley. The growing season was well advanced

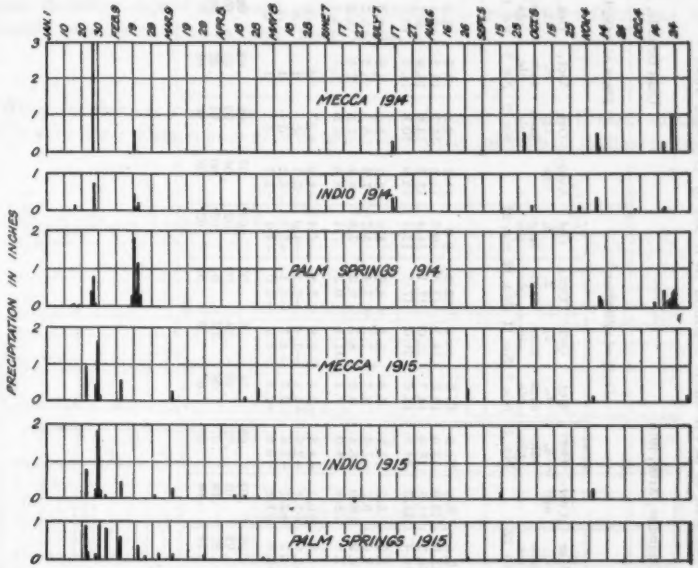

FIG. 7.—The daily rainfall in Coachella Valley, Calif., during 1914 and 1915 illustrating not only the character of the rains but the long periods of continuous droughts which occurred during the years when soil moisture studies were being made.

at that time, so that the available water had been considerably reduced. In many places the annuals had matured and were beginning to turn yellow and dry up. In comparing the available water in the creosote bush land of the two localities a difference of at least two weeks in the season of rapid growth must be taken into account. The sampling in creosote bush areas in the Coachella Valley was done March 2–3, and that in the Gila Valley March 15–27 (Tables VI and VII).

TABLE VII.—*Comparison of spring and fall soil conditions at the same stations in areas of creosote bush* [a]

Item	Depth of soil	Chandler, Ariz., 1915												Casa Grande, Ariz., 1915				
		Date of collection						Average	Date of collection					Average	Date of collection				Average
		Mar. 15, sample No. 1	Mar. 20, sample No. 9	Mar. 22, sample No. 10	Mar. 22, sample No. 11	Mar. 22, sample No. 12	Mar. 27, sample No. 22		Oct. 2, sample No. 1	Oct. 6, sample No. 9	Oct. 2, sample No. 11	Oct. 2, sample No. 12	Oct 5, sample No. 22		Oct. 11, sample No. 2	Oct. 11, sample No. 8	Oct. 11, sample No. 12	Oct. 12, sample No. 13	
	Feet																	
Moisture equivalent	1	10.0	7.3	10.8	10.6	10.2	9.5	9.8	11.3	13.9	10.2	12.2	9.0	11.3	9.6	9.5	9.3	9.3	9.4
	2	12.5	8.1	12.4	13.6	12.5	12.9	12.0	13.6	16.0	14.2	13.6	10.5	13.6	15.7	10.2	10.4	11.2	11.9
	3	14.8	10.4	12.9	17.0	15.2	18.2	14.8	15.4	14.7	16.0	17.1	14.4	15.5	13.9	13.9	9.7	11.4	12.2
	4	17.5	10.8	16.0	17.8	15.1	14.3	15.3	14.8	13.6	21.0	17.1	13.1	15.9	10.8	14.1	10.8	11.4	11.8
Wilting coefficient	1	5.4	4.0	5.9	5.8	5.5	5.2	5.3	6.1	7.6	5.5	6.6	4.9	6.1	5.2	5.2	5.1	5.1	5.2
	2	6.8	4.4	6.7	7.4	6.8	7.0	6.5	7.4	8.7	7.7	7.4	5.7	7.4	8.5	5.5	5.7	6.1	6.5
	3	8.0	5.7	7.0	9.2	8.3	9.9	8.0	8.4	8.0	8.7	9.3	7.8	8.4	7.6	7.5	5.3	6.2	6.7
	4	9.5	5.9	8.7	9.6	8.2	7.8	8.3	8.0	7.4	11.4	9.3	7.1	8.6	5.9	7.7	5.9	6.2	6.4
Moisture content above or below wilting coefficient.	1	+1.6	+0.3	+0.3	−0.6	+0.9	−1.8	+0.1	−4.4	−3.4	−3.8	−5.2	−4.4	−4.2	[b] d	d	d	d	-------
	2	+3.1	+2.2	+2.9	+2.0	+2.5	−2.9	+1.6	−2.9	−1.4	−3.4	−3.4	−4.3	−3.1	d	d	d	d	-------
	3	+4.4	+2.1	+5.7	+2.8	+3.3	−4.3	+2.3	−3.6	−2.3	−4.7	−5.1	−5.3	−4.2	d	d	d	d	-------
	4	+4.2	+1.7	+5.2	+3.8	−0.4	−3.6	+1.8	−3.6	−2.4	−4.0	−4.0	−4.7	−3.7	d	d	d	d	-------
Salt content	1	.03	.02	.02	.02	.02	.02	.02	.02	.24	.06	.02	.02	.07	.02	.02	.02	.02	.02
	2	.05	.02	.02	.06	.02	.02	.03	.02	.08	.04	.02	.02	.04	.02	.02	.02	.02	.02
	3	.06	.02	.02	.06	.06	.02	.04	.07	.08	.07	.04	.02	.06	.04	.02	.02	.02	.03
	4	.07	.06	.06	.07	.07	.14	.08	.06	.07	.20	.07	.02	.08	.06	.08	.07	.01	.05

[a] All data in this table are stated in percentages of the dry weight of the soil.
[b] d=dry soil.

In order to appreciate more fully the moisture conditions the reader should consult figure 8 which gives the daily rainfall in the Gila Valley during the years 1914 and 1915. The distribution of rainfall is much more uniform throughout this season than in Coachella Valley. A comparison on a monthly basis is shown in figure 9. A comparison of figures 7 and 8 with figure 9 in which the mean monthly record is shown will illustrate the great uncertainty as to quantity and distribution in these desert areas.

Salinity

Wherever there is a good growth of the creosote bush the salt content of the soil is very low. Even a poor growth indicates a stony infertile or shallow rather

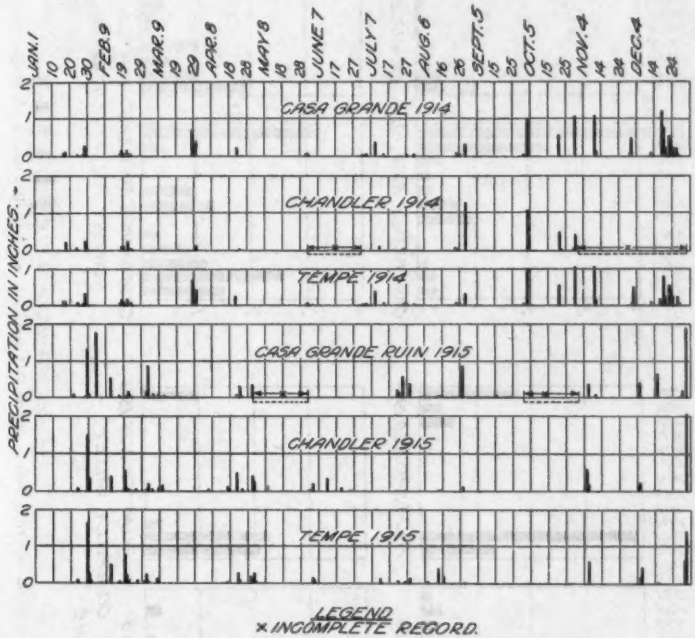

FIG. 8.—The daily rainfall in the Gila Valley, Ariz., during 1914 and 1915 illustrating not only the character of the rains but the long drought periods during the years when soil moisture studies were made.

than a saline soil (Table VIII). Individual plants of the creosote bush are sometimes found on soil containing considerable salt, but a good uniform growth has never been found on such soil. Those plants growing on saline soil are stunted and quite unlike the normal growth of the creosote bush. Comparing the creosote bush land of the two valleys (Tables VI and VII), the salt content is found to be greater in the Gila Valley. The quantity, while two or three times as great as that found in creosote bush land in Coachella Valley, is, nevertheless, small and, as far as farm crops are concerned, negligible.

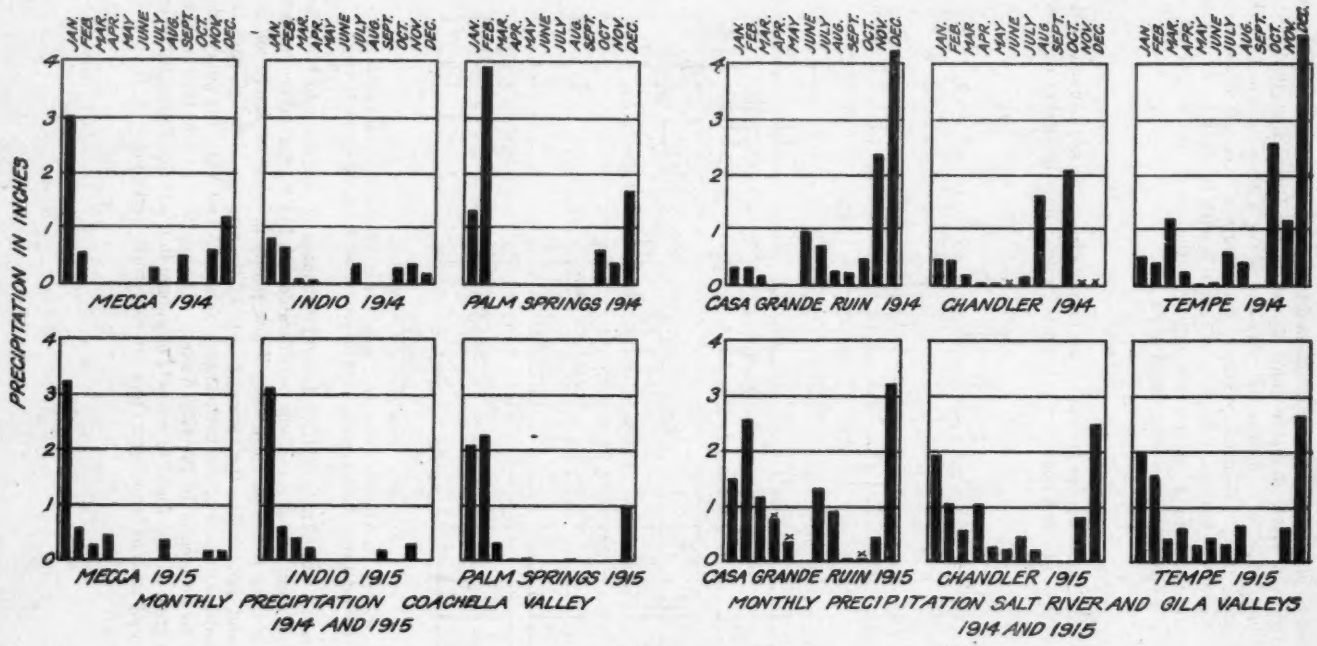

FIG. 9.—Mean monthly rainfall in the Coachella and Gila Valleys during 1914 and 1915, when studies were made of soil moisture conditions in these regions

TABLE VIII.—*A comparison of soil conditions in areas of good, medium, and poor growth of creosote bush, Chandler, Ariz., 1915* [a]

TABLE VIII.—*A comparison of soil conditions in areas of good, medium, and poor growth of creosote bush, Chandler, Ariz., 1915* [a]

Item	Depth of soil	Poor [b]			Average	Medium [b]		Average	Good [b]
		Sample No. 9	Sample No. 11	Sample No. 22		Sample No. 1	Sample No. 12		Sample No. 10
	Feet								
Moisture equivalent	1	10.6	10.4	9.3	10.1	10.7	11.2	10.9	10.8
	2	12.1	12.9	11.7	12.5	13.1	13.1	13.1	12.4
	3	12.6	16.5	16.3	15.1	15.1	16.2	15.6	12.9
	4	12.2	19.4	13.7	15.2	16.2	16.1	16.2	16.0
Wilting coefficient	1	5.8	5.7	5.1	5.8	5.8	6.1	6.0	5.9
	2	6.6	7.6	6.4	6.8	7.1	7.1	7.1	6.7
	3	6.9	9.0	8.9	8.3	8.2	8.8	8.5	7.0
	4	6.7	10.5	7.5	8.4	8.8	8.8	8.8	8.7
Moisture content above or below wilting coefficient		Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall
	1	+0.3 −3.4	−0.6 −3.8	−1.8 −4.4	−0.7 −3.9	+1.6 −4.4	+0.9 −5.2	+1.3 −4.8	+0.3 ----
	2	+2.2 −1.4	+2.0 −3.4	−2.9 −4.3	+0.5 −3.0	+3.1 −2.9	+2.5 −3.4	+2.8 −3.2	+2.9 ----
	3	+2.1 −2.3	+2.8 −4.7	−4.3 −5.3	+0.2 −4.1	+4.4 −3.6	+3.3 −5.1	+3.9 −4.4	+5.7 ----
	4	+1.7 −2.4	+3.8 −4.0	−3.6 −4.7	+0.3 −3.7	+4.2 −3.6	−0.4 −4.0	+1.9 −3.8	+5.2 ----
Salt content	1	0.13	0.04	0.02	0.06	0.03	0.02	0.03	0.02
	2	.05	.05	.02	.04	.04	.02	.03	.02
	3	.05	.07	.02	.05	.07	.05	.06	.02
	4	.07	.14	.08	.10	.07	.07	.07	.06

[a] All data given in this table are stated in percentages of the dry weight of the soil.
[b] Under each of the sample numbers above (as 9, 11, 22, etc.) the averages of the spring and fall soil conditions are given, except under moisture content, where averages were not made.

Summary of Physical Conditions

A good uniform growth of creosote bush indicates (1) at least 4 feet of light soils of coarse texture, very permeable and well drained, with a low run-off; (2) an abundant supply of available water in the upper 4 feet of soil after the winter rains, but none late in the summer; (3) a nonsaline soil to the depth of 4 feet. A poor growth of creosote bush indicates a coarse stoney infertile soil or a shallow soil having a hardpan or rocky layer within 2 or 3 feet of the surface or, more rarely, a saline subsoil.

ADAPTATION TO PHYSICAL CONDITIONS

In the warmer valleys, as the Coachella Valley, the growth of the creosote bush begins in February or sometimes earlier and ends before the hot summer months. During the summer and fall the plants are dormant, for by this time practically all the available soil moisture has been exhausted. The moisture in the surface foot of soil is exhausted by the large number of annuals that cover the spaces between the creosote bushes even up to the stems of the bushes themselves. The moisture below the surface foot is exhausted by the creosote bush. The creosote bush has no well-defined taproot but several almost equal branches parting near the surface of the ground (Pl. 4, B). These roots penetrate to considerable depths since the light texture of the soil and the deep penetration of the water favor a deep root system. The soil moisture here is exhausted before that of the desert-sage land and other areas in the lower parts of the valley, for the creosote bush covers the warmest slopes in the valley and therefore the annuals and the creosote bush plants start growth earlier in the spring. By May or June the annuals have matured and died while the creosote bush plants are dormant. The creosote bush lives through the long dry summer mainly because the small leathery leaves covered with a sticky resin favor a very low transpiration rate. When in a drought rest condition they become brownish and protect themselves by dropping many of the lower leaves.

EFFECTS OF DISTURBING FACTORS (SUCCESSIONS)

Creosote bush areas are not appreciably affected by grazing. The bushes are not browsed and the mechanical injury is slight. The herbaceous flora is, of course, greatly modified. Fires in the creosote bush areas are rare so that few opportunities have been offered for studying successions. Where the creosote bush has been cut Franseria probably precedes its return as a dominant plant.

VARIATIONS FROM THE TYPICAL ASSOCIATION

Creosote Bush and Bur-sage

Between the pure creosote bush areas and the foothills there is often a narrow tract occupied by a mixture of creosote bush and bur-sage (*Franseria dumosa* A. Gray) (Pl. 5, A). This mixture indicates a still lighter, coarser and very stony soil. The salt content is negligible, even less than in the typical creosote bush land. Bur-sage also occurs mixed with the creosote bush on the sandy knolls in the creosote bush areas.

Creosote Bush with Desert-sage

Creosote bush mixes with desert-sage (*Atriplex polycarpa* (Torr.) S. Wats.) (Pl. 5, B) near the line between these two associations. These mixed areas are very small in Coachella Valley, and indicate a higher salt content and heavier soil type than that of the typical creosote bush land, but less salt than that of

the desert-sage land (Table IX). Where the creosote bush is small, dwarfed, and scattered this is particularly true, but where the creosote bush is abundant and well developed, the salt content is negligible and the texture of the soil lighter. Where the growth of both creosote bush and desert-sage is good in this mixed area the land is among the best in this region. Its texture is somewhat lighter than typical desert-sage land, making cultivation easier and affording better drainage. The land is richer than creosote bush land and, compared to desert-sage land, there is less danger of its becoming saline. Its location makes irrigation possible where creosote bush land usually is too high.

TABLE IX.—*Comparison of spring and fall soil conditions at the same station in areas where creosote bush was mixed with desert-sage, Chandler, Ariz., 1915* [a]

Item	Depth of soil	Date of collection				Average	
		March 20, sample No. 8	October 5, sample No. 8	March 28, sample No. 27	October 5, sample No. 27	Spring	Fall
	Feet						
Moisture equivalent	1	6.9	6.4	10.0	11.2	8.5	8.8
	2	14.3	9.1	15.6	15.6	15.0	12.4
	3	20.0	15.7	16.0	16.8	18.0	16.3
	4	12.0	9.5	12.9	17.0	12.5	13.3
Wilting coefficient	1	3.8	3.5	5.4	6.1	4.6	4.8
	2	7.8	4.9	8.5	8.5	8.2	6.7
	3	10.9	8.5	8.7	9.1	9.8	8.8
	4	6.5	5.2	7.6	9.2	6.8	7.2
Moisture content above or below wilting coefficient	1	+1.1	−2.1	−1.3	−3.9	−0.1	−3.0
	2	+5.4	−1.4	+2.6	−1.1	+4.0	−2.3
	3	+4.8	−4.0	+0.7	−2.6	+2.8	−3.3
	4	+3.2	−2.7	−0.3	−2.8	+1.5	−2.8
Salt content	1	.02	.02	.06	.02	.04	.02
	2	.06	.02	.19	.12	.13	.07
	3	.27	.02	.46	.27	.37	.15
	4	.37	.06	.46	.32	.42	.19

[a] All data in this table are stated in percentages of the dry weight of the soil.

DESERT-SAGE ASSOCIATION

TOPOGRAPHICAL RELATIONS

The desert-sage association is one of the most important types of vegetation in the Southwestern deserts, but is not as wide in range as the creosote bush association. It is confined to southern Arizona and California, occurring only in the warmest valleys having a low altitude. In the Coachella and Gila Valleys it formerly covered larger areas than any other type of vegetation (figs. 2 and 3). At the present time much of the desert-sage land is under cultivation. It forms practically a continuous belt between the creosote bush area above and either the seepweed area or the saltbush and arrowweed area below. The best growth of desert-sage is found on the slightly sloping lands that are covered at certain times of the year by the flood waters from the adjoining hills. Wherever the slope of the land from foothills to valley floor is gradual, the change of soil conditions is also gradual, resulting in alternations and mixtures of the two types of vegetation. This gradual change also occurs at the lower edge of the desert-sage area where it frequently mixes with seepweed, mesquite thicket or narrowleaf saltbush.

BOTANICAL COMPOSITION

In the typical areas of this association the desert-sage (*Atriplex polycarpa* (Torr.) S. Wats.) is the only woody species present (figs. 10 and 11) with the exception of scattered mesquite (*Prosopis glandulosa* Torr.). In the Gila Valley (fig. 11), especially in the lower places, *Lycium parviflorum* A. Gray, *Lycium gracilipes* A. Gray, *Dondia intermedia* (S. Wats.) Heller and *Atriplex linearis*

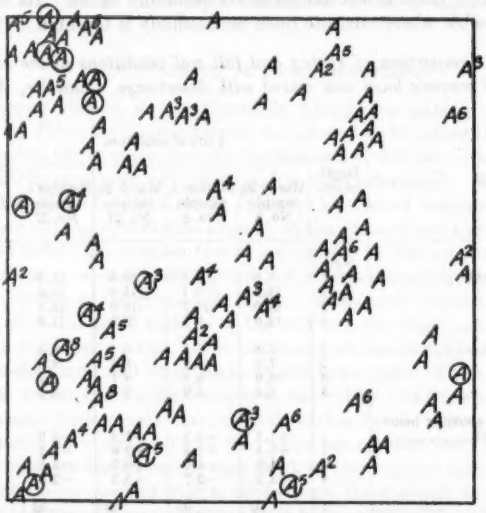

FIG. 10.—A 10-meter quadrat taken in a typical area of *Atriplex polycarpa* (Torr.) S. Wats. Individual, live plants of *Atriplex polycarpa* are indicated by *A;* dead plants by (A); and the number of stems to each plant by the small figures. Annuals were sparse and not blooming at this time. Mapped March 1, 1915, Indio, Calif.

S. Wats. are quite frequent. *Atriplex canescens* (Pursh) Nutt. is frequent in desert-sage areas in both valleys.

Lists containing all the perennial species noted in the desert-sage areas in Coachella and Gila Valleys are given below:

PERENNIAL SPECIES OF THE DESERT-SAGE ASSOCIATION IN COACHELLA VALLEY

Common or Frequent

Atriplex polycarpa (Torr.) S. Watts.
Prosopis glandulosa Torr.
Strombocarpa pubescens (Benth.) A. Gray.
Isocoma veneta acradenia (Greene) H. M. Hall.

Less Frequent or Rare

Asclepias subulata Decne.
Atriplex canescens (Pursh) Nutt.
Atriplex lentiformis (Torr.) S. Wats.
Covillea glutinosa (Engelm.) Rybd.
Dondia torreyana (S. Wats.) Standl
Eriodyction angustifolium Nutt.
Pluchea sericea (Nutt.) Coville.

PERENNIAL SPECIES OF THE DESERT-SAGE ASSOCIATION IN GILA VALLEY

Common or Frequent

Atriplex polycarpa (Torr.) S. Wats.
Lycium parviflorum A. Gray.
Lycium gracilepes A. Gray.
Atriplex canescens (Pursh) Nutt.
Atriplex linearis S. Wats.
Prosopis glandulosa Torr.

Less Frequent or Rare

Baccharis sp.
Isocoma wrightii (A. Gray) Rydb.
Sphaeralcea coulteri A. Gray.
Sphaeralcea fendleri A. Gray.

FIG. 11.—A 10-meter quadrat in a typical area of desert-sage, showing the location of each individual plant of *Atriplex polycarpa* (Torr.) S. Wats. indicated by *A*, and of *Atriplex canescens* (Pursh) Nutt., indicated by *Ac*, the only woody plants present. A circle around the letter indicates a dead plant. The small figures indicate the number of stems to each plant. See figure 12 for a detail of the annuals. Mapped March 29, 1915, Chandler, Ariz.

The number of annuals in the desert-sage areas as compared to that of the creosote bush or mesquite and chamiso areas is much smaller in both valleys. In Coachella Valley where flood waters frequently deposit a thin layer of silt which dries to form a crust, annuals often appeared only along the cracks in the silt. The number of annuals, both as to individuals and species, increases as the surface of the soil becomes lighter and more permeable. In the desert-sage areas *Plantago erecta* Morris is the most important annual in both valleys. In the Gila Valley *Baeria artistata* (Nutt.) Coville is also important (fig. 12).

The following lists give all the annual and biennial species noted in the desert-sage areas.

ANNUAL AND BIENNIAL SPECIES OF THE DESERT-SAGE ASSOCIATION IN THE GILA VALLEY

Common or Frequent

Plantago erecta Morris.
Festuca octoflora Walt.
Baeria chrysostoma Fisch. & Mey.
Lepidium lasiocarpum Nutt.
Poa bigelovii Vasey & Scribn.
Thelypodium lasiophyllum (Hook. & Arn.) Greene.
Baeria aristata (Nutt.) Coville.
Amsinckia menziesii (Lehm.) Nels. & Macbr.
Dipetalia subulata (Webb & Berth.) Kuntze.
Chylisma scapoidea (Nutt.) Small.
Eremalche exilis (A. Gray) Greene.
Bowlesia septentrionalis Coult. & Rose.
Pectocarya penicillata (Hook. & Arn.) A. DC.
Aster parviflorus A. Gray.
Conanthus demissus (A. Gray) Heller.
Matricaria matricarioides (Less.) Porter.

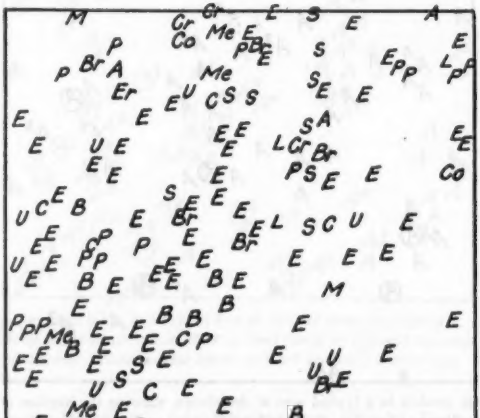

FIG. 12.—A 1-meter quadrat taken within the quadrat in figure 11 to show the annual flora of the desert-sage association. The letters give the location of each individual plant.

A = *Aster parviflorus* A. Gray.
B = *Baeria chrysostoma* Fisch. & Mey.
Br = *Festuca octoflora* Walt.
C = *Chylisma scapoidea* (Nutt.) Small.
Co = *Conanthus demissus* (A. Gray) Heller.
Cr = *Thelypodium lasiophyllum* (Hook. & Arn.) Greene.
E = *Baeria aristata* (Nutt.) Coville.
L = *Lappula occidentalis* (S. Wats.) Greene.
M = *Eremalche exilis* (A. Gray) Greene.
Me = *Mentzelia albicaulis* Dougl.
P = *Plantago erecta* Morris.
Pe = *Pectocarya penicillata* (Hook & Arn.) A. DC.
S = *Dipetalia subulata* (Webb. & Berth.) Kuntze.
U = *Spermolepis echinatus* (Nutt.) Heller.
Amsinckia menziesii (Lehm.) Nels. & Macbr. occurs around the desert-sage bushes.
Mapped March 29, 1915, Chandler, Ariz.

Less Frequent or Rare

Atriplex fasciculata S. Wats.
Evax multicaulis DC.
Calyptridium monandrum Nutt.
Cryptanthe sp.
Draba cuneifolia Nutt.
Erodium texanum A. Gray.
Erodium cicutarium (L.) L'Hér.
Gilia floccosa A. Gray.
Gilia inconspicua (J. E. Smith) Dougl.
Sphaeralcea sp.
Melilotus indica (L.) All.
Mentzelia albicaulis Dougl.
Monolepis nuttalliana (Schult.) Greene.
Plantago fastigiata Morris.
Nemoseris neomexicana (A. Gray) Greene.
Senecio sp.
Sonchus asper (L.) Hill.
Sophia glabra Woot. & Standl.
Spermolepis echinatus (Nutt.) Heller.
Microseris linearifolia (DC.) A. Gray.
Lappula occidentalis (S. Wats.) Greene.

ANNUAL AND BIENNIAL SPECIES OF THE DESERT-SAGE ASSOCIATION IN THE COACHELLA VALLEY

Common or Frequent

Plantago erecta Morris.
Eremalche exilis (A. Gray) Greene.
Dipetalia tubulata (Webb & Berth.) Kuntze.
Sophia pinnata (Walt.) Howell.
Mentzelia albicaulis Dougl.
Sphaerostigma veitchianum (Hook.) Small.
Conanthus demissus (A. Gray) Heller.
Amsinckia menziesii (Lehm.) Nels. & Macbr.

Less Frequent or Rare

Palafoxia linearis Lag.
Pectis papposa Harv. & Gray.

APPEARANCE

The gray of the desert-sage sets it off sharply from the creosote bush association even at considerable distances. A typical area shows a uniform shrubby growth (Pl. 6, B), about 3 feet high, the plants growing in clumps a few feet apart, but not nearly so widely spaced as the creosote bush. Mesquite trees are often scattered throughout this uniform growth of desert-sage. Each of the clumps is on a low hummock built up by soil that has been blown in around the bushes. The desert-sage is much smaller than the creosote bush and forms a dense rather than an open bush. There are several main branches coming up from the ground (Pl. 7, B) that are very crooked and very much branched at the top. In spring there is a dense covering of small grayish leaves on the new shoots. In fall most of the leaves have fallen off but there are large quantities of fruits.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

The type of soil covered by the desert-sage is almost a fine sandy loam (Tables X and XII). The moisture-holding capacity is therefore much greater than in the case of creosote bush. Due to the flood waters in Coachella Valley the surface of the soil is crusted with a layer of silt that is not easily penetrated by the water. This intermittent depositing of silt leads to a lack of uniformity of the subsoil, and there are often alternating layers of sand and silt in the third and fourth feet. The borings made in late summer show no available water to a depth of 4 feet. The desert-sage has not been found on the moister lands where there was available moisture in all 4 feet in the late summer. Even as early as March there was rarely any available moisture in the third or fourth foot. Sometimes only the first foot was wetted by winter rains (samples 4 and 5, Table X).

TABLE X.—*Comparison of spring and fall soil conditions at the same stations in typical areas of desert-sage, Indio, Calif., 1915* [a]

Item	Depth of soil	Date of collection					Average	Date of collection					Average
		Mar. 3, sample No. 1	Mar. 3, sample No. 2	Mar. 2, sample No. 3	Mar. 3, sample No. 4	Mar. 3, sample No. 5		Sept. 21, sample No. 1	Sept. 21, sample No. 2	Sept. 21, sample No. 3	Sept. 20, sample No. 4	Sept. 20, sample No. 5	
	Feet												
Moisture equivalent.	1	27.8	33.2	6.2	20.5	32.4	24.0	19.9	37.7	8.9	19.9	34.7	24.2
	2	24.9	36.5	6.4	27.4	34.4	25.9	18.0	39.2	12.3	20.7	41.5	26.3
	3	8.4	27.6	9.0	33.8	36.1	23.0	5.6	32.0	7.5	35.3	39.3	23.9
	4	20.1	9.0	4.3	29.3	33.0	19.1	29.1	15.2	6.9	27.8	32.9	22.4
Wilting coefficient.	1	15.1	18.0	3.4	11.2	17.6	13.1	10.8	20.4	4.8	10.8	18.9	13.2
	2	13.5	19.9	3.5	14.9	18.7	14.1	9.8	21.3	6.7	11.3	22.5	14.3
	3	5.0	15.0	4.9	18.4	19.6	12.6	3.0	17.4	4.1	19.2	21.4	13.0
	4	10.9	4.9	2.3	15.8	17.9	10.4	15.8	8.3	3.8	15.1	17.9	12.2
Moisture content above or below wilting coefficient.	1	−1.9	+7.0	+2.5	+6.0	+3.1	+3.3	−9.9	−18.2	−4.2	−1.7	−16.9	−10.2
	2	−1.6	+4.7	+1.1	−9.6	−9.1	−2.9	−5.3	−17.4	+0.9	−8.8	−12.1	−8.5
	3	−3.8	+0.3	−3.1	−10.2	−4.4	−4.2	−1.9	−13.6	−3.3	−11.9	−2.2	−6.6
	4	−7.2	−2.9	−1.4	−8.3	−5.9	−5.1	−9.5	−5.9	−1.3	−10.1	−6.2	−6.6
Salt content	1	.45	.06	------	.06	.46	.26	.18	.06	.32	.23	.44	.25
	2	1.16	.08	------	.06	1.48	.70	.38	.06	.14	.44	1.00	.40
	3	.32	.16	------	.35	.43	.32	.18	.10	.06	.30	.44	.22
	4	.39	.15	------	.23	.31	.27	.34	.13	.17	.20	.20	.21

[a] All data in this table are stated in percentages of the dry weight of the soil.

TABLE XI.—*Soil conditions in September and October in typical areas of desert-sage, Indio, Calif., 1914* [a]

TABLE XI.—*Soil conditions in September and October in typical areas of desert-sage, Indio, Calif., 1914* [a]

Item	Depth of soil	Date of collection: Sept. 15, sample No. 15	Sept. 19, sample No. 25	Sept. 22, sample No. 29	Sept. 24, sample No. 40	Sept. 24, sample No. 41	Sept. 25, sample No. 42	Sept. 25, sample No. 43	Sept. 25, sample No. 45	Sept. 26, sample No. 46	Sept. 26, sample No. 47	Sept. 28, sample No. 48	Sept. 29, sample No. 52	Sept. 30, sample No. 53	Date of collection: Oct. 1, sample No. 55	Oct. 6, sample No. 61	Oct. 9, sample No. 73	Oct. 10, sample No. 74	Oct. 10, sample No. 75	Oct. 13, sample No. 80	Oct. 15, sample No. 92	Oct. 22, sample No. 95a	Oct. 22, sample No. 95b	Oct. 22, sample No. 95c	Oct. 26, sample No. 97a	Oct. 26, sample No. 97b	Oct. 26, sample No. 97c	Average
Salt content	*Feet* 1	0.40	0.17	0.12	0.19	0.16	0.02	0.06	0.12	0.18	0.51	0.17	0.13	0.78	0.20	0.18	0.05	0.18	0.02	1.40	0.23	0.22	0.20	0.80	0.64	0.12	0.54	0.30
	2	.02	.54	.34	.31	.41	.01	.06	.10	1.64	.24	.16	.13	1.10	.40	.22	.07	.22	.18	1.18	.30	1.04	.20	.56	.80	.07	1.28	.45
	3	.02	.58	.22	.37	.28	.07	.24	.16	.78	.21	.76	.09	.72	.45	.21	.18	.24	.20	.23	.26	.23	.23	.19	.49	.06	1.21	.33
	4	.17	.42	.47	.28	.19	.06	.46	.10	.32	.21	.....	.06	.34	.24	.18	.08	.15	.23	.86	.32	.75	.72	.40	.19	.23	.32	.31
Water content [b]	1	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	-----
	2	sm	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	-----
	3	sm	sm	d	d	d	d	d	d	d	d	d	d	d	d	d	d	vsm	sm	nd	nd	d	d	d	nd	nd	nd	-----
	4	sm	sm	d	d	d	d	d	d	d	d	-----	d	d	d	d	d	vsm	sm	nd	sm	d	nd	nd	nd	nd	nd	-----
Soil type [c]	1	fsl	s	sl	sl	sl	s	sl	s	sl	sl	sl	s	sl	s	fsl	fsl	fsl	fsl	fsl	sl	fsl	fsl	fsl	sl	s	sl	-----
	2	fs	fs	s	fsl	sl	s	sl	s	fsl	fsl	s	s	sl	s	sl	fsl	sl	fsl	fsl	sl	fsl	fsl	fsl	sl	s	fsl	-----
	3	fs	fs	s	fsl	s	s	sl	sl	fsl	fsl	fsl	s	sl	s	sl	fsl	s	sl	s	s	s	s	s	sl	s	fsl	-----
	4	fs	sl	sl	fsl	s	s	sl	sl	fsl	sl	-----	s	sl	s	fsl	sl	s	sl	fsl	sl	fsl	fsl	fsl	s	s	sl	-----

[a] Salt content data in this table are stated in percentages of the dry weight of the soil. No moisture content or moisture equivalent determinations were made on the 1914 samples. Data given are field notes.

[b] sm=slightly moist; vsm=very slightly moist; nd=nearly dry; d=dry.

[c] f=fine; s=sand; l=loam.

Desert-sage in the Gila Valley indicates a soil texture (Table XII) differing very little from that of the creosote bush land, but much coarser than that of the desert-sage land in Coachella Valley (Table X). In the spring of 1915 there was available soil moisture to a depth of 4 feet. In the fall the moisture had been exhausted in the first and second feet of soil, but in some instances there was still available moisture in the third and fourth feet. This was due to the shallow root systems developed above a hard pan or heavy alkaline soil (Table XIII). That the available soil moisture was greater in spring than that in the creosote bush land was due probably to the creosote bush being on higher and warmer lands where growth begins earlier in the spring and uses the available soil moisture sooner. At the time these samples were taken, the latter part of March, the annuals on the creosote bush land were already beginning to wither and turn yellow. Those on the desert-sage land were still in their prime. At Casa Grande the soil texture of desert-sage land is much like that at Chandler, but lighter than in Coachella Valley. There is no water available in any of the 4 feet of soil in the fall.

TABLE XII.—*A comparison of spring and fall soil conditions at the same stations in typical areas of desert-sage*

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TABLE XII.—*A comparison of spring and fall soil conditions at the same stations in typical areas of desert-sage* [a]

Item	Depth of soil	Chandler, Ariz., 1915																	Casa Grande, Ariz., 1915			
		Date of collection								Average	Date of collection								Average	Date of collection			Average
		Mar. 16, sample No. 3	Mar. 20, sample No. 5	Mar. 20, sample No. 6	Mar. 20, sample No. 7	Mar. 25, sample No. 16	Mar. 25, sample No. 17	Mar. 26, sample No. 19	Mar. 28, sample No. 26		Oct. 3, sample No. 3	Oct. 5, sample No. 5	Oct. 5, sample No. 6	Oct. 5, sample No. 7	Oct. 1, sample No. 16	Oct. 1, sample No. 17	Oct. 6, sample No. 19	Oct. 5, sample No. 26		Oct. 11, sample No. 1	Oct. 11, sample No. 7	Oct. 12, sample No. 14	
	Feet																						
Moisture equivalent	1	9.9	16.8	19.8	16.8	11.6	6.1	8.2	11.5	12.6	8.7	14.9	18.5	13.0	10.5	6.8	8.7	12.9	11.7	10.4	10.2	9.1	9.9
	2	13.9	17.9	11.9	18.4	18.1	6.9	8.6	21.7	14.7	11.5	17.4	10.8	21.4	16.5	7.6	9.4	21.6	14.5	13.7	13.5	12.8	13.3
	3	17.3	15.2	11.7	22.6	16.9	8.5	10.2	21.9	15.5	19.3	13.3	11.0	21.3	18.8	8.2	11.8	21.9	15.7	19.5	14.5	10.9	15.0
	4	19.7	12.9	13.9	15.4	15.0	8.2	11.6	19.2	14.5	20.9	14.0	12.6	14.2	27.2	8.4	13.9	18.9	16.3	18.7	11.9	10.7	13.8
Wilting coefficient	1	5.4	9.1	10.8	9.1	6.3	3.3	4.5	6.2	6.8	4.7	8.1	10.1	7.1	5.7	3.7	4.7	7.0	6.4	5.7	5.5	5.0	5.4
	2	7.6	9.7	6.5	10.0	9.8	3.8	4.7	11.8	8.0	6.2	9.5	5.9	11.6	8.9	4.1	5.1	11.7	7.9	7.4	7.3	7.0	7.2
	3	9.4	8.3	6.4	12.0	9.2	4.6	5.5	11.9	8.4	10.5	7.2	6.0	11.6	10.2	4.5	6.4	11.9	8.5	10.6	7.9	5.9	8.1
	4	10.7	7.0	7.5	8.4	8.2	4.5	6.3	10.4	7.9	11.4	7.6	6.9	7.7	14.9	4.6	7.6	10.3	8.9	10.2	6.5	5.8	7.5
Moisture content above or below wilting coefficient.	1	+2.8	+4.0	+0.9	+2.8	−0.8	+0.3	−0.6	−1.2	+1.0	−3.2	−5.7	−5.2	−4.6	−3.3	−2.3	−3.5	−4.3	−4.4	[b] d	d	d	-------
	2	+6.5	+6.5	+2.7	+2.6	+1.9	+2.3	+0.9	+4.2	+3.5	+0.9	−3.9	−3.1	−4.0	−1.7	−0.3	−1.8	−2.1	−2.0	d	d	d	-------
	3	+6.4	+4.3	+1.4	−2.4	+4.8	+2.4	+1.5	+3.2	+2.7	+2.9	−1.5	−2.6	−1.9	+3.5	+2.5	−2.9	+0.8	+0.1	d	d	d	-------
	4	+8.1	+4.0	−3.2	−2.9	+0.7	+3.7	+2.6	+1.6	+3.0	+3.7	−2.5	−3.4	−2.4	+7.7	+3.6	−2.3	−1.4	+0.4	d	d	d	-------
Salt content	1	.06	.05	.02	.10	.06	.02	.01	.02	.04	.02	.06	.12	.02	.16	.11	.01	.14	.08	.02	.02	.07	.04
	2	.46	.06	.06	.80	.10	.03	.02	.14	.21	.19	.04	.06	.31	.34	.35	.01	.59	.25	.02	.02	.17	.07
	3	.94	.05	.07	.44	.38	.27	.02	.63	.35	.51	.02	.02	.37	.62	.41	.04	.72	.34	.04	.06	.22	.08
	4	1.06	.06	.02	.44	.94	.44	.06	.86	.49	.21	.02	.02	.32	.82	.41	.15	.83	.35	.04	.19	.19	.14

[a] All data in this table are stated in percentages of the dry weight of the soil.

[b] d=dry soil.

TABLE XIII.—*A comparison of soil conditions in areas of good, medium, and poor growth of desert-sage, Chandler, Ariz., 1915* [a]

Item	Depth of soil	Poor [b]			Mean	Medium [b]		Mean	Good [b]			Mean
		Sample No. 3	Sample No. 7	Sample No. 26		Sample No. 16	Sample No. 17		Sample No. 5	Sample No. 6	Sample No. 19	
Moisture equivalent	Feet											
	1	9.3	14.9	12.2	12.1	11.1	6.5	8.8	15.9	19.2	8.5	14.5
	2	12.7	19.9	21.7	18.1	17.3	7.3	12.3	17.7	11.4	9.0	12.7
	3	18.3	21.7	21.9	20.6	17.9	8.4	13.2	14.3	11.4	11.0	12.2
	4	20.3	14.8	19.1	18.1	21.1	8.3	14.7	13.5	13.3	12.8	13.2
Wilting coefficient	1	5.1	8.1	6.6	6.6	6.0	3.5	4.8	8.6	10.5	4.6	7.9
	2	6.9	10.8	11.8	9.8	9.4	4.0	6.7	9.6	6.2	4.9	6.9
	3	10.0	11.8	11.9	11.2	9.7	4.6	7.2	7.8	6.2	6.0	6.7
	4	11.1	8.1	10.4	9.9	11.6	4.6	8.1	7.3	7.2	7.0	7.2
Moisture content above or below wilting coefficient.		Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall
	1	+2.8 −3.2	+2.8 −4.6	−1.2 −4.3	+1.5 −4.0	−0.8 −3.3	+0.3 −2.3	−0.3 −2.8	+4.0 −5.7	+0.9 −8.2	−0.6 −3.5	+1.4 −5.8
	2	+6.5 +0.9	+2.6 −4.0	+4.2 −2.1	+4.4 −1.7	+1.9 −1.7	+2.3 −0.3	+2.1 −1.0	+6.5 −3.9	+2.7 −3.1	+0.9 −1.8	+3.4 −2.9
	3	+6.4 +2.9	−2.4 −1.9	+3.2 +0.8	+2.4 +0.6	+4.8 +3.5	+2.4 +2.5	+3.6 +3.0	+4.5 −1.5	+1.4 −2.6	+1.5 −2.9	+2.5 −2.3
	4	+8.1 +3.7	−2.9 −2.4	+1.6 −1.4	+2.3 0.0	+9.7 +7.7	+3.7 +4.6	+6.0 +6.2	+4.0 −2.5	−3.2 −3.4	+2.6 −2.3	+1.1 −2.7
Salt content	1	0.04	0.06	0.08	0.06	0.11	0.07	0.09	0.06	0.07	0.01	0.05
	2	.33	.56	.37	.42	.22	.19	.21	.05	.06	.02	.04
	3	.73	.41	.68	.61	.50	.34	.42	.04	.05	.03	.04
	4	.64	.38	.85	.62	.88	.43	.66	.04	.02	.11	.06
Field notes on hardpan, gravel, lime, etc.	1	Sandy										
	2	Heavy soil.	Lime and hardpan.	Lime and hardpan.								
	3	Veins of white salt.				Lime						
	4	do				do						

[a] All data in this table are stated in percentages of the dry weight of the soil.

[b] Averages of spring and fall figures were made except under moisture content.

Salinity

The salt content of desert-sage land is shown in Tables X, XI, and XII. All of the 4 feet of soil show appreciable quantities of salt, and vary considerably. This is more easily understood if the fact is considered that pure areas of desert-sage may be either of a good growth, 3 to 4 feet high, or poor scrubby growth, 1 to 2 feet high. Samples taken in these two extremes of the plant growth in Coachella Valley show considerable difference in the salt content (Table XIV). A typical desert-sage area of a good growth indicates land having a negligible amount of salt. The average amount of salt of all the samples in the desert-sage is much higher than a similar average of the creosote bush samples (Table XXXIV). The abrupt changes in the salinity as well as the texture and moisture of the soil follow closely the abrupt changes of the elevation and slope of the land covered by these two associations.

The desert-sage in the Gila Valley indicates a lower salt content in the first two feet of soil than in the Coachella Valley. With the exception of the first foot, the salt content is four times as great as in the creosote bush land. On the whole, a typical area of desert-sage indicates land that is not too saline for farming purposes. The salt content of the soil varies with the growth and conditions of the plants forming the area. If, as in the case of the Coachella Valley data the data in Table XII is separated into three groups, according to the field notes on the growth and conditions of the plants, whether poor, medium, or good (Table XIII) it will be seen that the salt content is much less in the good group while it rises considerably, especially in the third and fourth feet, in the poor group.

The salt content is lower in desert-sage land in the Gila Valley, somewhat higher in the Coachella Valley, and negligible around Casa Grande where it has approximately the same salt content as the creosote bush land of the Gila Valley.

Summary of Physical Conditions

The desert-sage indicates land of a much finer texture and greater moisture-holding capacity than the creosote bush land. The penetration of the water, however, is much less on the desert-sage land, due to the heavier soil and layer of silt so often deposited on the surface as a result of flood water following the winter rains. A good growth of desert-sage in the Gila Valley indicates land that has a soil texture ranging from a sandy to a fine sandy loam, and somewhat coarser than that indicated by the same plant in the Coachella Valley. There is available moisture to a depth of 4 feet in spring, but none in the fall. The amount of available water is therefore much less than on the creosote bush land. The salt content is much higher in the desert-sage land though, wherever there is a good growth of desert sage, the salt content of the soil is negligible. Where the growth is poor the salt content is greater, but never excessive.

TABLE XIV.—*A comparison of soil conditions in areas of good, medium, and poor growth of desert-sage, Indio, Calif., 1915* [a]

Item	Depth of soil	Poor	Medium		Average	Good		Average
		Sample No. 1	Sample No. 4	Sample No. 5		Sample No. 2	Sample No. 5	
	Feet							
Moisture equivalent	1	23.9	20.2	33.6	26.9	35.5	7.6	21.6
	2	21.5	24.1	38.0	31.1	37.9	9.4	23.7
	3	7.0	34.6	37.7	36.2	29.8	8.3	19.1
	4	24.6	28.6	33.0	30.8	12.1	5.6	8.9
Wilting coefficient	1	13.0	11.0	18.3	14.7	19.2	4.1	11.7
	2	11.7	13.1	20.6	16.9	20.6	5.1	12.9
	3	4.0	18.8	20.5	19.7	16.2	4.5	10.4
	4	13.4	15.5	17.9	16.7	6.6	3.1	4.9
Moisture content above or below wilting coefficient		Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall	Spring Fall
	1	−1.9 −9.9	+ 6.0 − 1.7	+3.1 −16.9	+4.6 − 9.3	+7.0 −18.2	+2.5 −4.2	+4.8 −11.2
	2	−1.6 −5.3	− 9.6 − 5.8	−9.1 −12.1	−9.4 −10.5	+4.7 −17.4	+1.1 +0.9	+2.9 − 8.3
	3	−3.8 −1.9	−10.2 −11.9	−4.4 − 2.2	−7.3 − 7.1	+0.3 −13.6	−3.1 −3.3	−1.7 − 8.5
	4	−7.2 −0.5	− 8.3 −10.1	−5.9 − 6.2	−7.1 − 8.2	−2.9 − 5.9	−1.4 −1.3	−2.2 − 3.6
Salt content	1	0.32	0.15	0.45	0.30	0.06	0.32	0.19
	2	.77	.25	1.24	.75	.07	.14	.11
	3	.25	.33	.44	.39	.13	.06	.10
	4	.37	.22	.26	.24	.14	.17	.16

[a] All data in this table are stated in percentages of the dry weight of the soil. Averages of the spring and fall data were made except under moisture content.

ADAPTIONS TO PHYSICAL CONDITIONS

The desert-sage has a well developed tap root besides numerous supplementary roots just below the surface of the ground (Pl. 7, B). Plants of good growth feed on at least 3 to 4 feet of soil, but those of poor growth, where the penetration of water is less, do not feed below 2 feet. In general, the period of growth of the desert-sage corresponds to that of the creosote bush but since the areas covered by the former are not so favorably situated with regard to temperature, the beginning of the season's growth of the desert-sage lags about two weeks behind that of the creosote bush. This difference is reflected in the growth of the annuals. In 1915 in the middle of February annuals were in bloom in the creosote-bush areas, but were not blooming up to March 1 in the desert-sage areas. During the summer months the leaves are shed until by fall the plant is bare except for the fruits, which, in favorable years, are so heavy that when they have fallen they cover the ground. The desert-sage has to resist the most severe drought conditions of any of the plant associations in Coachella Valley. The areas having the poorest growth were found next to the seepweed, or, in the Gila Valley, near narrowleaf saltbush where the salt content is high, especially below the surface foot. The areas of the best growth were those at the upper end of the desert-sage belt bordering the sand hills or the creosote bush areas.

The number of annuals on the desert sage land is very small compared to that of the creosote bush land and therefore the moisture of the surface foot is not exhausted by them as in the case of the creosote bush land. As there are depressions between the desert-sage bushes where the water accumulates after rains, the plants avail themselves of this surface moisture by means of the superficial part of their root systems.

EFFECTS OF DISTURBING FACTORS (SUCCESSIONS)

In Coachella Valley, when a typical desert-sage area is destroyed by fire or cultivation, *Isocoma veneta acradenia* (Greene) H. M. Hall takes a prominent place in the successions, preceded by annuals and biennials and followed by desert-sage. This is well illustrated when the vegetation along the roads (Pl. 6, A) is destroyed for use in "brushing" the roads. The strips where the vegetation has been destroyed are then dominated by Isocoma, while the rest remains as virgin desert-sage.

In places having more favorable moisture conditions, that is, land formerly cultivated, the seepweed, arrowweed, or saltbush may act as a weed in an early stage of the successions until the moisture is somewhat exhausted, which may then be followed by Isocoma, and, finally, by desert sage.

VARIATIONS FROM THE TYPICAL ASSOCIATIONS

The desert-sage mixes with the creosote bush association above it, and with the seepweed association below. The former has been discussed as a variation of the creosote bush association; the latter will be discussed under the seepweed association.

MESQUITE THICKET

TOPOGRAPHICAL RELATIONS

The mesquite thicket has a wider range than the creosote bush, extending as far west as the creosote bush and much farther east into Texas. The mesquite thickets occupy the lowest land in the valleys. The largest and densest areas occur along the river bottoms where the land is subirrigated, but these give way to desert-sage as the land rises gradually toward the mountains.

BOTANICAL COMPOSITION

A typical mesquite thicket contains no other trees or shrubs than the mesquite (*Prosopis glandulosa* Torr.). In a large part of the area where the mesquite dominates, however, there are several other shrubs mixed with it. Here *Atriplex polycarpa* (Torr.) S. Wats., *Dondia intermedia* (S. Wats.) Heller, *Atriplex linearis* S. Wats., and *Lycium parviflorum* A. Gray are found on low hummocks between the mesquite trees. These hummocks are accumulations of light soil, usually sand, blown about by the wind and lodged around the bushes.

APPEARANCE

The appearance of a mesquite thicket depends on the abundance of the trees. Where conditions are favorable the mesquite trees form impenetrable thickets.

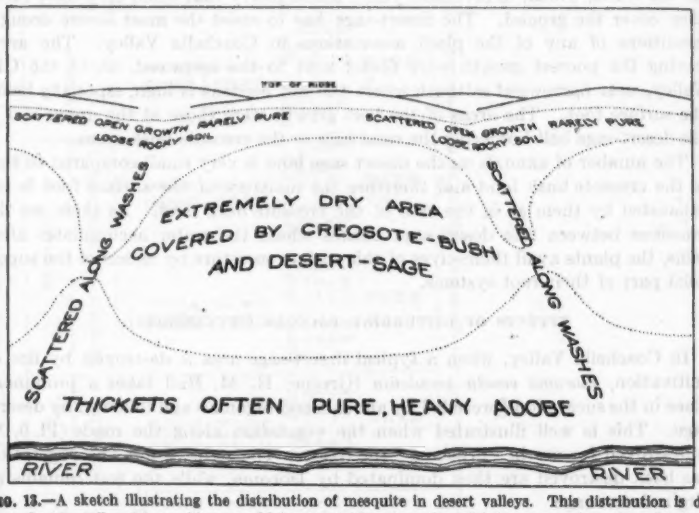


FIG. 13.—A sketch illustrating the distribution of mesquite in desert valleys. This distribution is dependent on soil moisture, either on a high water table, where the soil is heavy or, where the soil is loose and rocky as at the base of slopes and along water courses, on the deep penetration of flood waters following rains.

But in the large areas where the mesquite mixes with the desert-sage, there are wide open spaces covered with hummocks of desert-sage and sometimes seepweed.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

Like the seepweed, the mesquite grows in two very distinct zones, with regard to soil moisture: (*a*) Areas in the lowlands where the water table is high, but not high enough for such shrubs as saltbush, seepweed or arrowweed. Here the growth is best, forming dense, often impenetrable, thickets. The soil is heavy, a clay loam, and usually saline, but not excessively so; (*b*) areas along washes and on hillsides where it is mixed with other plants forming the "hills mixed" association just above the creosote bush association or the areas in the sandhills where it is mixed with chamiso (Fig. 13). The soil of the areas in the second group is just the opposite of the bottom lands, being either almost pure sand or in the "hills mixed" areas a stony, loose loam, well drained and non-

saline. The penetration of water in the rainy season is deep but the water table is beyond the reach of the root system. The growth here is scattered and open, the individual trees being smaller, scarcely forming a trunk and resembling large shrubs.

The texture of soil indicated by the mesquite thickets is like that of the desert-sage land. Sample 14, Table XXVII, shows the first foot considerably lighter, because it was taken on a hummock, otherwise it would show heavier soil. The main difference in the two types of land is in the soil moisture. In the mesquite land the water table influences the soil moisture. The third and fourth feet were not found dry as late as October. In spring there is an abundance of water in all 4 feet.

Salinity.

The salt content is appreciable in all 4 feet and is especially high in the third and fourth feet (sample 14, Table XXVII).

Summary of Physical Conditions Indicated

The mesquite thickets indicate land with (1) a soil texture approximately that of desert-sage land; (2) water table high but never actually coming to the surface of the soil; (3) an abundance of available water in all 4 feet in spring, and some water in the third and fourth feet even late in fall; (4) an appreciable quantity of salt in all 4 feet, the quantity increasing in the third and fourth feet.

ADAPTATIONS TO PHYSICAL CONDITIONS

The mesquite has a very wide range of adaptability as to the soil conditions under which it grows, from a nonsaline type that is practically pure dune sand to the saline heavy adobe lands at the bottoms of the valley. It is on the latter type that the pure dense mesquite thickets occur, often so dense as to be almost impenetrable.

The mesquite puts out a new set of leaves in the early spring and carries a dense foliage throughout the hot months. Most of these leaves are lost in the winter. Mesquite blooms in the spring, and in late summer or early fall bears ripe fruit pods which were used to a large extent as food by the Indians. This tree thrives best on a heavy soil that is subirrigated, and rarely forms a good sized tree on lands where its roots can not reach underground water.

Mesquite thicket land covers considerable areas in the Gila Valley. This land is subject to flooding by the water from lands above, but could probably be used for growing crops after leaching out some of the salts without providing artificial drainage.

NARROWLEAF SALTBUSH ASSOCIATION

TOPOGRAPHICAL RELATIONS

Narrowleaf saltbush (*Atriplex linearis* S. Wats.), has a much more limited range than desert-sage. It is not found in Coachella Valley. In the Gila Valley it occupies the low flat depressions occurring either in the creosote bush or in the desert-sage areas. The center of these flat areas is either a "bare flat" ("slick land") or a seepweed area. Surrounding this is the narrowleaf saltbush area and outside of this area again is a scrubby growth of creosote bush or desert-sage. At the lines of contact between these types are considerable areas of narrowleaf saltbush mixed with seepweed or desert-sage, and, more rarely, with creosote bush.

BOTANICAL COMPOSITION

Typical areas of narrowleaf saltbush (*Atriplex linearis* S. Wats.) contain no other shrubs. Usually *Atriplex polycarpa* (Torr.) S. Wats. *Prosopis glandulosa*

Torr., *Dondia intermedia* (S. Wats.) Heller and *Lycium parviflorum* A. Gray are scattered throughout the area. In places the annual *Atriplex fasciculata* S. Wats. is abundant after the summer rains.

APPEARANCE

At a distance narrowleaf saltbush areas are hard to separate from those of desert-sage. At closer range the narrowleaf saltbush appears much smaller and lighter colored, but it has larger leaves than the desert-sage and more of them are retained so that less of the dark stems show.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

Narrowleaf saltbush indicates a hard compacted red soil at from 4 to 18 inches below the surface. The soil above is loose and lighter. In fall all 4 feet were dry with no moisture available. There are indications that water collects in these areas after the rains so that at this time there is a good supply of available moisture, at least in the upper lighter soil.

Salinity

The salt content of the lighter layer above the red compacted soil is not very high (Table XV), but that of the compacted subsoil is considerably higher. Where narrowleaf saltbush mixes with creosote bush the salt content is much lower (Table XVI).

Summary of Physical Conditions Indicated

Typical areas of narrowleaf saltbush indicate: (1) A heavy compacted subsoil with a lighter layer of soil 4 to 18 inches in depth; (2) no available moisture in the fall in any of the 4 feet of soil but probably a good supply in the upper, light layer of soil after the rainy season; (3) a small quantity of salts in the light layer of soil but ranging over ½ per cent in the compact subsoil. Narrowleaf saltbush indicates a much shallower soil than desert-sage.

TABLE XV.—*Soil conditions in typical areas of narrowleaf saltbush, Casa Grande, 1915* [a]

Item	Depth of soil	Date of collection: Oct. 11 sample No. 3 [b]	Date of collection: Oct. 12 sample No. 15	Average
	Feet			
Moisture equivalent	1	21.9	21.4	21.7
	2	21.4	25.6	23.5
	3	18.3	22.5	20.4
	4	20.4	31.3	25.8
Wilting coefficient	1	11.9	11.6	11.8
	2	11.6	13.9	12.8
	3	9.9	12.2	11.1
	4	11.1	17.0	14.1
Moisture content above or below wilting coefficient	1	d	[c] d	----------
	2	d	d	----------
	3	d	d	----------
	4	d	d	----------
Salt content	1	.15	.17	.16
	2	.34	.24	.29
	3	.22	.98	.60
	4	.25	.91	.58

[a] All data in percentages of the dry weight of the soil.
[b] Sample No. 3 was taken in a narrowleaf saltbush flat surrounded by creosote bush. See Table XVI for sample taken where narrowleaf saltbush and creosote bush mix at the border line of this same flat. Sample No. 15 was taken in a narrowleaf saltbush flat surrounded by desert-sage.
[c] d=dry soil.

TABLE XVI.—*Soil conditions in an area of narrowleaf saltbush mixed with a poor growth of creosote bush, Casa Grande, Ariz., 1915* [a, b]

Item	Depth of soil	Date of collection Oct. 11, sample No. 4
	Feet	
Moisture equivalent	1	31.4
	2	22.2
	3	35.7
	4	32.2
Wilting coefficient	1	17.1
	2	17.5
	3	19.4
	4	17.5
Moisture content above or below wilting coefficient.	1	[c] d
	2	d
	3	d
	4	d
Salt content	1	.11
	2	.20
	3	.24
	4	.36

[a] All data in percentages of the dry weight of the soil.
[b] The creosote bush measured from 1 to 2½ feet high.
[c] d=dry soil.

ADAPTATIONS TO PHYSICAL CONDITIONS

Narrowleaf saltbush has a very shallow root system limiting itself to the upper layer of loose soil. More leaves are retained than in the case of the desert-sage, and the fruits here are not produced in as great quantities.

SALTGRASS ASSOCIATION

TOPOGRAPHICAL RELATIONS

Large saltgrass areas are not as common in the Southwestern desert region as they are in the Great Basin.

In the Gila Valley the saltgrass areas are insignificant, occurring only as scattered small meadows along the river. In Coachella Valley the pure areas of saltgrass, that is, the meadows, are small, rarely several acres in extent, and are scattered throughout the flat and poorly drained land, the area covered by the pickleweed, the saltbush, and the arrowweed. Saltgrass also occurs in all parts of the valley around springs, flowing wells, and reservoirs.

BOTANICAL COMPOSITION

The saltgrass meadows are usually a sod of pure *Distichlis spicata* L. Greene, but sometimes there are scattered plants of *Cressa truxillensis* H. B. K. *Allenrolfea occidentalis* (S. Wats.) Kuntze, *Dondia torreyana* (S. Wats.) Standl., *Dondia intermedia* (S. Wats.) Heller, *Pluchea sericea* (Nutt.) Coville, or *Atriplex lentiformis* (Torr.) S. Wats. may be mixed in at the outer edge, according to which of the plant groups border the meadow.

APPEARANCE

The meadows show a very uniform growth of saltgrass, practically excluding all other plants (Pl. 8, A.)

In late winter and early spring (January, February, and March) the meadows have a "cured grass" color, the saltgrass having made but little growth. Later in the season, however, and until late fall the color is fresh green.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

Saltgrass indicates a heavy soil where the water table comes up to or very near the surface. There is an abundance of available water all the year; even the first foot rarely becomes dry (Tables XVII and XVIII).

Salinity

The salt content of saltgrass land is higher than that of any other type of land, with the exception of pickleweed land (Table XXXIV). The average salt content of the 4 feet of soil is over 1 per cent (Tables XVII and XVIII.) Considerable quantities of black alkali often occur in the third and fourth feet, as, for instance, in Table I, sample 8, which represents the fourth foot in a saltgrass meadow, over 26 per cent of the total salt content were bicarbonates and 6 per cent carbonates.

Summary of Physical Conditions Indicated

Saltgrass land is very saline and has a high water table. In order to use this land for growing farm crops profitably, it is necessary to drain the land and leach out some of the salts. Saltgrass, however, is eaten by stock, so that this land in its natural state affords pasturage. In some places it is even cut for hay.

ADAPTATIONS TO PHYSICAL CONDITIONS

The range of tolerance of saltgrass is very great. On salt flats it is often found pushing into the most extremely saline soils. Where flood water is carried over an area it develops a relatively luxuriant growth, and it will do well in nonsaline soils. This grass spreads by root stalks, and these are pushed gradually out into the salt flats. It also has the ability to remain dormant for a long period and grow again when rain or flood waters leach to some extent the saline surface soil and replenish the soil moisture supply.

TABLE XVII.—*Soil conditions in September and October in typical areas of saltgrass, Indio, Calif., 1914* [a]

Item	Depth of soil	Date of collection			Average
		Sept. 14, sample No. 12	Oct. 13, sample No. 77	Oct. 14, sample No. 86	
	Feet				
Salt content	1	>2.50	>2.50	0.39	1.80
	2	.73	1.56	1.40	1.23
	3	.48	1.66	.68	.94
	4	.56	1.32	.19	.69
Water content [a]	1	[b] m	d	w	
	2	m	2/3 d, 1/3 m	w	
	3	m	m	w	
	4	w	m	w	
Soil type [c]	1	[c] cl	sl	fsl	
	2	cl	sl	fsl	
	3	c	l	sl	
	4	c	sl	sl	

[a] No soil moisture or moisture equivalent determinations were made on the soil samples of 1914. The data given are merely the field notes on the samples. Salt content data are stated in percentages of the dry weight of the soil.

[b] m=moist soil; d=dry soil; w=wet soil.

[c] s=sand or sandy; l=loam; fsl=fine sandy loam; c=clay.

TABLE XVIII.—*Comparison of spring and fall soil conditions at the same stations in typical areas of saltgrass, Indio, Calif., 1915* [a]

Item	Depth of soil	Date of collection		Average	Date of collection		Average
		Mar. 5, sample No. 21	Mar. 5, sample No. 22		Sept. 22, sample No. 21	Sept. 22, sample No. 22	
	Feet						
Moisture equivalent	1	27.1	27.1	27.1	23.5	35.8	29.7
	2	14.9	27.6	21.3	13.8	26.7	20.3
	3	36.7	34.2	35.5	29.0	31.2	30.1
	4	16.4	28.6	22.5	13.7	28.2	21.0
Wilting coefficient	1	14.7	14.7	14.7	12.8	19.5	16.2
	2	8.1	15.0	11.6	7.5	14.5	11.0
	3	20.0	18.6	19.3	15.8	17.0	16.4
	4	8.9	15.6	12.3	7.4	15.3	11.4
Moisture content above or below wilting coefficient.	1	+18.3	+14.2	+16.3	+10.1	+0.7	+5.4
	2	+22.2	+12.6	+17.4	+13.7	+5.8	+9.8
	3	+16.8	+17.3	+17.1	+18.0	+10.5	+14.3
	4	+24.6	+14.1	+19.4	+19.4	+16.0	+17.7
Salt content	1	>2.50	2.40	2.45	>2.50	1.66	2.08
	2	2.24	.30	1.27	1.90	.74	1.32
	3	.41	.30	.36	1.16	.89	1.03
	4	.26	.13	.20	.47	.58	.53

[a] All data in percentages of the dry weight of the soil.

WASHINGTON PALMS

TOPOGRAPHICAL RELATIONS

The Washington palm is peculiar to Coachella Valley. The palms occur as scattered groups around springs or streams. The most of these are in the part of the valley above Indio, although in groups of two or three they extend down beyond Mecca. The most striking groups are those north of Indio where the palms make extensive groves just next to the barren clay hills (Pl. 9). Large groups are also found above Palm Springs where the palms follow the mountain streams for several miles.

BOTANICAL COMPOSITION

Where the palm trees (*Washingtonia filifera* Wendl.) grow around springs in the heavier soils there is usually a sod of *Distichlis spicata* (L.) Greene. In the group north of Indio *Juncus robustus* S. Wats. and *Imperata hookerii* Rupr. are associated with the *Distichlis*. On the lower places the *Distichlis* is mixed with *Juncus cooperi* Engelm. and *Scirpus olneyi* A. Gray. Along the streams in the hills the soil is rockier and the vegetation growing with the palms is characteristic of the washes, previously discussed under the Yucca and cactus association.

APPEARANCE

Because of the height and the contrast with the low, shrubby vegetation surrounding them, the palm groups make a striking appearance and can be seen for long distances. This is not true of the one or two trees often found at the springs in the flats, where scattered mesquite trees tend to hide the palms. The trees are often 50 feet or more in height, with a trunk about 2 feet in diameter. At the end of the growing season the leaves merely droop and dry but do not fall off, so that the upper part of the trunk is entirely hidden by the mass of old leaves (Pl. 9).

PHYSICAL CONDITIONS INDICATED

Soil Moisture

These palm groups always indicate a good supply of moisture either from springs or mountain streams available all the year.

Salinity

A single test of the upper 15 inches of soil taken in the group of palms north of Indio showed only a small amount of salt, 0.16 per cent. The surface of the soil where this group occurs is crusted with white salt, mostly sulphates (Table I, sample 4).

SUMMARY OF PHYSICAL CONDITIONS, AND ADAPTATIONS

The palm trees indicate a good supply of water available all the year. The soil, although saline, is not excessively so, due probably to the constant supply of comparatively fresh water from the subsoil.

Since water is available throughout the summer and since high temperatures are necessary for the palm's growth, most of its growth is made during the summer.

PICKLEWEED ASSOCIATION

TOPOGRAPHICAL RELATIONS

The pickleweed areas, like the saltgrass areas, are not as common or extensive in the Southwestern desert region as in the Great Basin. Pickleweed covers the central and lower portions of Coachella Valley (fig. 2). The area covered is a more or less continuous strip, very broad at the edge of the Salton Sea, where it is coming in as an early stage of a succession on the saline soil as the water recedes, and narrowing toward the upper part of the valley into a narrow strip along the bottom of a dry creek. In the Gila Valley and throughout the rest of the Southwestern desert region there is but little pickleweed, and where it does occur it is mixed with other plants in small areas usually along the rivers.

BOTANICAL COMPOSITION

While most of this area in Coachella Valley is pure pickleweed (*Allenrolfea occidentalis* (S. Wats.) Kuntze) it is often associated with scattered plants of saltgrass (*Distichlis spicata* (L.) Greene), arrowweed (*Pluchea sericea* (Nutt.) Coville), *Atriplex lentiformis* (Torr.) S. Wats., *Atriplex canescens* (Pursh) Nutt. and *Dondia torreyana* (S. Wats.) Standl. No annuals are found here because of the high salt content of the surface of the soil.

APPEARANCE

The areas in Coachella Valley consist of large flat tracts bearing scattered plants of pickleweed. The spaces between the plants are white with a heavy coating of salts (Pl. 8, B). A typical area shows dark bushy brownish-green plants from 1 to 2 feet high. Large tracts of this kind are monotonous in appearance. In the early spring the plants are brown, the parts above ground dying in winter.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

The soil is more permeable than that of the desert-sage land. The texture in the third and fourth feet is considerably lighter than that of the desert-sage land (Table XIX). The soil moisture (Tables XIX and XX) is greatly increased by the high water table. In spring the water comes almost to the surface and the land is very boggy, more so than any other type of land in the valley. While the saltgrass land is very wet, the sod formed tends to make it firmer on the surface. In the fall the surface foot of soil is no longer boggy, but there is a good supply of available moisture in all 4 feet of soil.

TABLE XIX.—*Comparison of spring and fall soil conditions at the same stations in typical areas in the pickleweed association, Indio, Calif., 1915* [a]

Item	Depth of soil	Date of collection: Mar. 4, sample No. 26	Mar. 5, sample No. 27	Mar. 5, sample No. 28	Average	Date of collection: Sept. 22, sample No. 26	Sept. 22, sample No. 27	Sept. 23, sample No. 28	Average
	Feet								
Moisture equivalent	1	21.1	21.7	26.4	23.1	21.5	18.9	21.5	20.6
	2	16.0	24.1	29.1	23.1	20.0	19.9	29.9	23.2
	3	21.2	11.7	21.6	18.2	23.2	11.0	20.1	18.1
	4	20.0	13.1	17.8	17.0	7.1	9.1	15.0	10.4
Wilting coefficient	1	11.5	11.8	14.4	12.6	11.7	10.3	11.7	11.2
	2	8.7	13.1	15.8	12.5	10.9	10.8	16.3	12.7
	3	11.5	6.4	11.8	9.9	12.6	6.0	10.9	9.8
	4	10.9	7.1	9.7	9.2	3.9	5.0	8.1	5.6
Moisture content above or below wilting coefficient.	1	+16.1	+15.3	+21.0	+17.5	+1.8	+8.2	+7.3	+5.8
	1	+12.3	+16.0	+20.0	+16.1	+5.2	+10.8	+11.2	+9.1
	3	+12.6	+24.0	+18.5	+18.4	+7.1	+15.3	+17.3	+13.2
	4	+15.7	+21.7	+25.1	+20.8	+6.2	+12.5	+16.7	+12.0
Salt content	1	>2.50	>2.50	>2.50	>2.50	>2.50	>2.50	>2.50	>2.50
	2	>2.50	2.50	.59	1.86	2.20	1.73	.20	1.38
	3	>2.50	.65	.36	1.17	1.45	1.10	.20	.92
	4	.68	.36	.40	.48	.24	.91	.18	.44

[a] All data in percentages of the dry weight of the soil.

TABLE XX.—*Soil conditions in September and October in typical areas of the pickleweed association, Indio, Calif., 1914* [a]

Item	Depth of soil	Date of collection: Sept. 14, sample No. 9	Sept. 22, sample No. 32	Oct. 2, sample No. 58	Oct. 14, sample No. 85	Oct. 15, sample No. 89	Oct. 15, sample No. 94	Oct. 31, sample No. 103	Average
	Feet								
Salt content	1	1.90	2.10	>2.50	.36	>2.50	2.10	1.01	1.78
	2	.40	1.52	1.96	1.73	1.04	>2.50	1.10	1.46
	3	.21	2.30	.70	1.50	.76	1.96	1.01	1.21
	4	.18	1.56	.29	.68	.16	1.56	1.04	.78
Water content	1	m [b]	d	w	w	w	d	w	----
	2	w	m	w	w	w	sm	w	----
	3	w	m	w	w	w	m	w	----
	4	w	m	w	w	w	m	w	----
Soil type	1	l [c]	fsl	fsl	sl	sl	sl	c	----
	2	l	fsl	fsl	sl	sl	sl	c	----
	3	sl	fsl	fsl	fsl	fsl	fsl	c	----
	4	l	fsl	fsl	fsl	fs	fsl	c	----

[a] No soil moisture or moisture equivalent determinations were made on the soil samples of 1914. The data given are merely the field notes on the samples. Salt content data are stated in percentages of the dry weight of the soil.

[b] m=moist soil; d=dry soil; sm=slightly moist soil; w=wet soil.

[c] l=loam; s=sand or sandy; f=fine; c=clay.

Salinity

Pickleweed indicates land that has an excessive amount of salt in the first and second feet, and often the third (Tables XIX and XX). The fourth foot is least saline, averaging approximately one-half of 1 per cent (Table XXXIV). The average salt content for the 4 feet of soil is about 1½ per cent. In places there is a uniform white layer of salt on the surface that resembles a covering of snow.

Summary of Physical Conditions

Pickleweed indicates land with a lighter texture than that of the desert-sage, with a high-water table that comes to the surface in early spring and furnishes an abundant supply throughout the year, and an excessive salt content rarely less than 1 per cent in the first foot and averaging 1½ per cent for all 4 feet of soil.

ADAPTATIONS TO PHYSICAL CONDITIONS

Pickleweed is limited to soils where the water table reaches the surface of the soil for at least a part of the year. The soil surface is typically encrusted with salt. It has a relatively deep root system and is able to thrive in a water-saturated, strongly saline soil (Pl. 10, A). It can endure more water and more salt than seepweed.

MESQUITE AND CHAMISO COMMUNITY

TOPOGRAPHICAL RELATIONS

This type of vegetation covers the sand hills of the region. In Coachella Valley (fig. 2) the greater part of this area lies in the upper part of the valley, below the creosote bush and breaking in on what would otherwise be occupied by desert-sage. At Myoma the area extends practically across the valley. The hills themselves vary a great deal in size and form, from the low mounds representing the old dunes covered with vegetation to the barest hills formed by the newly drifted sand. They are formed by the light soil picked up by the winds blowing down San Gorgonio Pass and deposited some distance farther down the valley.

In the Gila Valley (fig. 3) a modification of this association is of minor importance. It covers low sandy knolls and ridges scattered in the valley just southwest of Chandler, and is in the midst of the desert-sage association.

BOTANICAL COMPOSITION

There are several important woody plants in this area as well as a large number of annuals. The chamiso (*Atriplex canescens* (Pursh) Nutt.) is the most important woody species in this type of vegetation where the slope is not so steep. The mesquite (*Prosopis glandulosa* Torr.) covers the tops of the sandhills and, sometimes, all of the lower and older ones. On some of the oldest hills creosote bush is the most important shrub. *Isocoma veneta acradenia* (Greene) H. M. Hall is important in places and *Parosela emoryi* (A. Gray) Heller quite frequent. The areas of depression between the hills where silt has been washed in is occupied by desert-sage (*Atriplex polycarpa* (Torr.) S. Wats.)

The number of species of annuals is large, comparing favorably with the creosote bush land. They do not cover the ground as completely as on creosote bush land, but on the contrary are often widely spaced, no single species predominating. The plants found in this area are given in the following list:

PERENNIAL SPECIES OF THE MESQUITE AND CHAMISO

Common or Frequent

Prosopis glandulosa Torr.
Atriplex canescens (Pursh) Nutt.
Covillea glutinosa (Engelm.) Rydb.
Isocoma veneta acradenia (Greene) H. M. Hall.
Abronia villosa S. Wats.
Psathyrotes ramosissima (Torr.) A. Gray.
Atriplex polycarpa (Torr.) S. Wats.
Parosela emoryi (A. Gray) Heller.
Geraea eriocephala (A. Gray) Blake.

Less Frequent or Rare

Atriplex hymenelytra (Torr.) S. Wats.
Chilopsis linearis (Cav.) Sweet.
Isomeris arborea Nutt.
Parosela arborescens (Torr.) Heller.
Petalonyx thurberi A. Gray.
Lepidospartum squamatum A. Gray.

ANNUAL AND BIENNIAL SPECIES OF THE MESQUITE AND CHAMISO

Common or Frequent

Anogra trichocalyx (Nutt.) Small.
Chylisma scapoidea (Nutt.) Small.
Dithyrea californica Harv.
Sphaerostigma veitchianum (Hook.) Small.
Cryptanthe sp.
Eremocarya micrantha (Torr.) Greene.
Palafoxia linearis Lag.
Achyronychia cooperi Torr. & Gray.
Eriogonum thomasii Torr.
Eremalche exilis (A. Gray) Greene.

Less Frequent or Rare

Baileya panciradiata Harv. & Gray.
Calyptridium monandrum Nutt.
Croton californicus Muell. Arg.
Plantago erecta Morris.
Sophia pinnata (Walt.) Howell.
Stillingia annua Muell. Arg.
Thelypodium lasiophyllum (Hook. & Arn.) Greene.

APPEARANCE

The chamiso is greener than the desert-sage and is considerably taller. In early spring, just after the new growth has come on, the plants are very green. In the latter part of summer most of the leaves have dropped (Pl. 11, B) but large quantities of fruits cover the smaller branches. In favorable years the fruit is so abundant that the branches bend under its weight.

The mesquite trees growing on the soil occupied by the mesquite and chamiso association have a distinct form. On the drier heavier soils occupied by the desert-sage, or the wetter saline soils occupied by the saltbush and arrowweed, the mesquite grows as a tree with a single large trunk often more than 13 inches in diameter. On the sand hills, however, the mesquite is shrubby, sprawling over large spaces of ground and forming small thickets. On some of the newer dunes these are partly buried under the sand so that only the smaller branches are seen above the surface (Pl. 10, B). The mesquite begins growth only after warm weather sets in, as the leaves do not appear until March. Up to that time they are leafless and reddish-brown, due to the color of the bark of the branches and twigs. From March on, throughout the long hot summer, they retain a heavy foliage.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

The soil is practically a pure sand on the hills with a little silt in the depressions. It is very readily permeable, with practically no run-off, and has a very low moisture holding capacity, as is shown in Table XXI. Immediately after the winter rains there is water available to a depth of 4 feet. The surface foot is dried out rapidly by the annuals and by evaporation. By summer there is no available water to a depth of 4 feet. However, in cases where the hills are bare and the water has not been used by the plants there is available water in the third and fourth feet even as late as September (sample 16, Table XXI).

TABLE XXI.—*Comparison of spring and fall soil conditions at the same stations in typical areas of mesquite and chamiso, Indio, Calif., 1915* [a]

Item	Depth of soil	Date of collection					Average	Date of collection					Average
		Mar. 3, sample No. 16	Mar. 2, sample No. 17	Mar 2, sample No. 18	Mar. 2, sample No. 19	Mar. 2, sample No. 20		Sept. 20, sample No. 16	Sept. 21, sample No. 17	Sept. 21, sample No. 18	Sept. 23, sample No. 19	Sept. 23, sample No. 20	
	Feet												
Moisture equivalent	1	2.3	2.0	2.6	2.1	2.7	2.3	2.4	3.1	3.3	2.2	2.2	2.6
	2	2.9	3.0	2.9	2.5	2.3	2.7	2.9	3.3	2.7	2.6	2.7	2.8
	3	2.8	3.4	2.5	2.2	1.9	2.6	3.3	3.9	1.9	2.7	2.4	2.8
	4	2.6	3.1	3.0	2.6	2.6	2.8	3.8	4.5	2.2	2.6	2.3	3.1
Wilting coefficient	1	1.3	1.1	1.4	1.1	1.5	1.3	1.3	1.7	1.8	1.2	1.2	1.4
	2	1.6	1.6	1.6	1.3	1.3	1.5	1.6	1.8	1.5	1.4	1.5	1.6
	3	1.5	1.9	1.4	1.2	1.0	1.4	1.8	2.1	1.0	1.5	1.3	1.5
	4	1.4	1.7	1.6	1.4	1.4	1.5	2.1	2.4	1.2	1.4	1.3	1.7
Moisture content above or below wilting coefficient	1	+2.5	+2.2	+3.1	+2.1	+2.1	+2.4	−1.2	−1.5	−1.7	−1.0	−1.1	−1.3
	2	+3.8	+3.8	+3.5	+3.9	+3.9	+3.8	0.0	−1.6	−1.0	−1.2	−1.1	−1.0
	3	+4.1	+5.9	+2.4	+3.0	+4.8	+4.1	+0.9	−1.7	+0.5	−1.2	0.0	−0.3
	4	+0.8	+1.0	+0.1	−0.2	+0.5	+0.4	+0.8	−1.6	+1.1	−0.9	−0.1	−0.1
Salt content	1	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.02	<.01	<.01	.01
	2	<.01	<.01	<.01	<.01	.01	<.01	.01	<.01	<.01	<.01	.02	.01
	3	.02	<.01	<.01	<.01	.06	.02	<.01	.01	<.01	<.01	.02	.01
	4	.02	.03	.02	.02	.02	.02	.02	.02	.12	<.01	.01	.04

[a] All data in this table are stated in percentages of the dry weight of the soil.

Salinity

The salt content of the soils of this area is very low (Table XXI), which is expected in soil that is practically pure sand.

Summary of Physical Conditions

The lands covered by mesquite and chamiso show: (1) Practically a pure sand with very good penetration and low run-off, but low moisture-holding capacity; (2) a good supply of moisture after the winter rains to a depth of 4 feet; (3) a very low salt content.

ADAPTATIONS TO PHYSICAL CONDITIONS

The chamiso begins growth much earlier than the mesquite and because of its shallower root system (Pl. 11, B) makes use of the moisture collected in the upper 4 feet of soil during the rainy season. As soon as the weather becomes hot some of the lower leaves fall off so that by late summer the plants are almost leafless but bear large quantities of fruit.

Since the moisture supply of the mesquite is not so limited, and since it sends its roots to a greater depth, it is therefore much less conservative than the chamiso in regard to water loss in the hot months of the year.

The mesquite and chamiso land in the Coachella Valley is capable of crop production where the sand hills are not too high. Some of the lower and older dunes where water from artesian wells was available have already been leveled and planted to dates, and it is apparent that a large part of this area can be so utilized.

VARIATIONS FROM THE TYPICAL COMMUNITY

Chamiso

In the Gila Valley (fig. 3) the chamiso (*Atriplex canescens* (Pursh) Nutt.) covers long low narrow sandy ridges not at all like the high, wind-blown sand hills of the Coachella Valley. Here the half-buried abnormal growth of the mesquite is lacking. Chamiso is often the only shrubby species, though frequently there is found an *Isocoma wrightii* (A. Gray) Rydb. and, more rarely, *Baccharis sarothroides* A. Gray or *Sphaeralcea coulteri* A. Gray. The annuals are abundant (Pl. 11, A). Among them are some showy large-flowered species.

The following list includes all the plants found in this community:

PERENNIAL SPECIES OF CHAMISO

Common or Frequent

Atriplex canescens (Pursh) Nutt.
Isocoma wrightii (A. Gray) Rydb.
Prosopis glandulosa Torr.

Less Frequent or Rare

Baccharis sarothroides A. Gray.
Sphaeralcea coulteri A. Gray.

ANNUAL AND BIENNIAL SPECIES

Common or Frequent

Thelypodium lasiophyllum (Hook. & Arn.) Greene.
Conanthus demissus (A. Gray) Heller.
Pectocarya penicillata (Hook. & Arn.) A. DC.
Baeria chrysostoma Fisch. & Mey.
Festuca octoflora Walt.
Anogra albicaulis (Pursh) Britton.
Plantago erecta Morris.
Pachylophus sp.
Mentzelia albicaulis Dougl.
Dipetalia subulata (Webb & Berth.) Kuntze.
Machaeranthera parviflora A. Gray.
Chylisma scapoidea (Nutt.) Small.
Amsinckia menziesii (Lehm.) Nels. & Macbr.

Less Frequent or Rare

Eriogonum thurberi Torr.
Erodium texanum A. Gray.
Draba cuneifolia Nutt.
Lappula occidentalis (S. Wats.) Greene.
Eremalche exilis (A. Gray) Greene.
Conanthus demissus (A. Gray) Heller.
Matricaria matricarioides (Less.) Porter.
Phacelia sp.
Sophia glabra Woot. & Standl.
Spermolepis echinatus (Nutt.) Heller.

The moisture equivalents are low, especially in the upper 2 feet of soil (Table XXII). The moisture-holding capacity therefore is not high, but the penetration is such that it is not likely that any water runs off during rainfall. Available water was found in the first 4 feet of soil in March. In October, available water was present in a very small quantity in the fourth foot only.

In three out of the four borings in this type of land the salt content was very low in all 4 feet. In one case (sample 13, Table XXII) the readings were much higher, especially below the first foot. There was considerable lime in small lumps scattered throughout the lower depths. From the standpoint of growing crops these quantities of salts would not be of great importance.

Chamiso ("sand bars") in the Gila Valley indicates (1) a light sandy soil; (2) soil moisture available in spring in all 4 feet of soil; and (3) a low salt content.

These areas are not extensive enough to be of great importance agriculturally. However, they can be farmed. In some cases they have been leveled and used for truck crops.

ARROWWEED AND SALTBUSH COMMUNITY

TOPOGRAPHICAL RELATIONS

This community is unimportant outside of Coachella Valley. It is confined to "seep" areas or subirrigated strips of land along the rivers. The areas in Coachella Valley occupied by the mixture of arrowweed and saltbush occur almost entirely below a line drawn east and west through Thermal (fig. 2). Above this there are only narrow strips along the dry creeks. The areas are very irregular in form and are disconnected, usually skirting the pickleweed area and coming just within that covered by seepweed.

TABLE XXII.—*A comparison of spring and fall soil conditions at the same stations in typical areas of chamiso "sandbars," Chandler, Ariz., 1915*[a]

Item	Depth of soil	Date of collection				Average	Date of collection				Average
		Mar. 16, sample No. 2	Mar. 25, sample No. 13	Mar. 25, sample No. 18	Mar. 26, sample No. 20		Oct. 1, sample No. 2	Oct. 1, sample No. 13	Oct. 1, sample No. 18	Oct. 7, sample No. 20	
	Feet										
Moisture equivalent	1	6.4	6.4	6.4	5.5	6.2	6.4	9.4	7.0	6.0	7.2
	2	7.9	8.6	6.7	6.4	7.4	8.2	9.8	7.8	6.7	8.1
	3	15.7	10.0	6.8	6.7	9.8	15.2	12.5	7.4	7.4	10.5
	4	14.8	14.0	6.0	6.4	10.3	20.2	13.7	7.6	7.9	12.4
Wilting coefficient	1	3.5	3.5	3.5	3.0	3.4	3.5	5.1	3.8	3.2	3.9
	2	4.3	4.7	3.6	3.5	4.0	4.5	5.3	4.2	3.6	4.4
	3	8.5	5.4	3.7	3.6	5.3	8.3	6.8	4.0	4.0	5.8
	4	8.0	7.6	3.3	3.5	5.6	11.0	7.4	4.1	4.3	6.7
Moisture content above or below wilting coefficient.	1	+2.0	+1.7	−0.2	+1.4	+1.2	−2.7	−4.2	−2.8	−2.8	−3.1
	2	+3.6	+3.7	+1.8	+3.5	+3.2	−2.0	0.0	−1.6	−1.3	−1.3
	3	+5.3	+5.9	+2.6	+2.0	+4.0	−1.5	+2.3	−1.1	−1.0	−0.3
	4	+5.6	+4.9	+3.2	+3.7	+4.4	−1.1	+2.8	−0.5	−0.8	+0.1
Salt content	1	.01	.06	.01	.01	.02	.02	.02	.01	.01	.02
	2	.01	.02	.01	.01	.01	.02	.40	.01	.01	.11
	3	.02	.11	.01	.02	.04	.02	.38	.01	.01	.11
	4	.02	.61	.01	.01	.16	.02	.50	.07	.01	.15

[a] All data in this table are stated in percentages of the dry weight of the soil.

BOTANICAL COMPOSITION

While the arrowweed (*Pluchea sericea* (Nutt.) Coville) (Pl. 12, B) and the saltbush (*Atriplex lentiformis* (Torr.) S. Wats.) (Pl. 12, A) also occur separately as pure types, the areas of each are very small.

In Coachella Valley the two are nearly always intermingled, often with additional plants of *Isocoma veneta acradenia* (Greene) H. M. Hall, *Dondia torreyana* (S. Wats.) Standl. and *Prosopis glandulosa* Torr. Here, as in the case of the seepweed area, the salt crust on the surface of the soil excludes all annuals. In the Gila Valley, shrubs found mixed with the arrowweed and saltbush are *Dondia intermedia* (S. Wats.) Heller, *Isocoma wrightii* (A. Gray) Rydb. and *Atriplex canescens* (Pursh) Nutt. Here, as in Coachella Valley, no annuals were found.

APPEARANCE

This type of vegetation shows a very rank, dense, shrubby growth, often 6 feet high or higher. In favorable places the shrubbery is so thick as to be scarcely penetrable; more often, however, there are open spaces of several feet between the plants, which are usually covered with a heavy alkaline crust (Pl. 12, A)

PHYSICAL CONDITIONS INDICATED

Soil Moisture

The land occupied by the arrowweed and saltbush type of vegetation in Coachella Valley is characterized by the same soil texture as that of the pickleweed land. The first 2 feet are of considerably finer texture than the third and fourth (Table XXIV). The soil moisture is influenced to a large extent by the high-water table, so that there is an available water supply all the year round below the surface foot (Tables XXIII and XXIV). In spring, the water comes almost to the surface of the soil, although not as high as in the pickleweed land.

Salinity

The average amount of salt in the first foot of this type of land of all the samples in Coachella Valley is more than 1½ per cent (Table XXXIV). The average for the second foot is over ¾ per cent, and for the third and fourth about ½ per cent. The decrease in salinity is probably due to the light texture of the soil underlying the upper 2 feet and to the constant addition of water that is only slightly saline.

Summary of Physical Conditions

Arrowweed and saltbush land in Coachella Valley are characterized by (1) a soil, the upper 2 feet of which is quite comparable to that of the pickleweed land, but underlying which there is a much coarser soil; (2) a high water-table making moisture available, at least below the surface foot, all the year round; and (3) usually a high salt content in the surface foot, considerably less so in the second, and moderate amounts in the third and fourth feet.

ADAPTATIONS TO PHYSICAL CONDITIONS

In Coachella Valley, the arrowweed and saltbush are usually mixed, especially on lands that have been disturbed or have become saturated from flooding or seepage. On flooded lands these plants remain only until the water is exhausted and then give way to the desert-sage or more drought-resistant shrubs.

In seepage or constantly flooded areas, if the supply of moisture remains sufficient, the plants develop to their fullest and form the thickets mentioned. Though the soil requirements of these two plants are alike to a great extent, the arrowweed can endure much drier soil conditions, while the saltbush can withstand soils that are much more saline.

TABLE XXIII.—*Soil conditions in September and October in areas of saltbush, mixed areas of saltbush and arrowweed, and in areas of arrowweed, Indio, Calif., 1914*[a]

Item	Depth of soil	Saltbush			Saltbush and arrowweed			Arrowweed						
		Date of collection			Date of collection			Date of collection						
		Sept. 29, sample No. 50	Oct. 15, sample No. 91	Average	Oct. 14, sample No. 82	Oct. 14, sample No. 83	Average	Sept. 15, sample No. 18	Sept. 6, sample No. 60	Oct. 7, sample No. 65	Oct. 7, sample No. 68	Oct. 7, sample No. 69	Oct. 7, sample No. 70	Average
	Feet													
Salt content	1	>2.50	>2.50	>2.50	2.10	0.28	1.19	0.07	0.23	0.26	>2.50	0.43	0.36	0.64
	2	.19	.68	.44	.21	1.10	.66	.06	.19	.24	1.20	.22	.24	.33
	3	.24	.19	.22	.22	1.10	.66	.02	.18	.21	.96	.22	.20	.30
	4	.11	.12	.12	.11	1.28	.70	.12	.22	.18	.82	.20	.20	.29
Water content	1	*b* w	w	------	sa	w	-----	nd	d	d	w	d	d	-----
	2	w	w	------	sa	w	-----	sm	sm	sm	w	d	sm	-----
	3	w	w	------	sa	w	-----	sm	sm	sm	w	sm	m	-----
	4	w	w	------	sa	w	-----	sm	sm	m	w	m	m	-----
Soil type	1	*c* sl	fsl	------	fsl	fsl	-----	fsl	sl	fsl	sl	fsl	fsl	-----
	2	sl	fsl	------	fsl	fsl	-----	fsl	sl	fsl	sl	fsl	fsl	-----
	3	sl	fsl	------	fsl	fsl	-----	fsl	sl	fsl	sl	fsl	fs	-----
	4	sl	fsl	------	sl	sl	-----	fsl	c	fsl	sl	fsl	fs	-----

[a] No soil moisture or moisture equivalent determinations were made on the 1914 soil samples. The data given are the field notes on the soil samples. Salt content data are stated in percentages of the dry weight of the soil.

[b] d=dry soil; nd=nearly dry soil; m=moist soil; sm=slightly moist soil; w=wet soil; sa=saturated soil.

[c] s=sand or sandy; l=loam; fsl=fine sandy loam; c=clay.

TABLE XXIV.—*Comparison of the spring and fall soil conditions at the same stations in typical areas of saltbush and arrowweed, Indio, Calif., 1915*[a]

Item	Depth of soil	Date of collection			Average	Date of collection			Average
		Mar. 4, sample No. 31	Mar. 4, sample No. 32	Mar. 5, sample No. 33		Sept. 23, sample No. 31	Sept. 23, sample No. 32	Sept. 23, sample No. 33	
	Feet								
Moisture equivalent	1	22.5	32.9	29.5	28.3	24.5	32.4	26.5	27.8
	2	10.0	23.6	25.3	19.6	22.2	19.0	24.0	21.7
	3	4.1	20.0	23.9	16.0	14.0	20.8	24.7	19.8
	4	4.7	13.2	23.0	13.6	25.2	11.8	19.3	18.8
Wilting coefficient	1	12.2	17.8	16.0	15.3	13.3	17.6	14.4	15.1
	2	5.4	12.8	13.8	10.7	12.1	10.4	13.1	11.9
	3	2.2	10.9	13.0	8.7	7.6	11.3	13.4	10.8
	4	2.6	7.2	12.5	7.4	13.7	6.4	10.5	10.2
Moisture content above or below wilting coefficient.	1	+9.4	+13.3	+19.7	+14.1	+1.9	−8.6	+6.7	0.0
	2	+8.5	+13.2	+15.8	+12.5	+7.1	−2.2	+7.5	+4.1
	3	+4.7	+13.2	+18.1	+12.0	+5.9	−3.8	+10.2	+4.1
	4	+8.1	+18.9	+22.2	+16.4	+8.4	−1.9	+18.4	+8.3
Salt content	1	>2.50	>2.50	>2.50	>2.50	>2.50	1.72	2.18	2.13
	2	1.06	.32	.50	.63	2.50	1.04	.52	1.35
	3	0.32	.16	.35	.28	1.10	.19	.20	.50
	4	0.28	.15	.16	.20	1.18	.16	.14	.49

[a] All data in this table are stated in percentage of the dry weight of the soil.

Both of the plants develop in the summer and have dense foliage during the driest part of the year. In November most of the leaves are dead. The plants remain in this dormant condition until warm weather the next season.

Arrowweed and saltbush land, when cultivated for a time and then abandoned, soon reverts to the same type of vegetation without an intermediate stage. If this land is cleared, irrigated, and planted, bare spots eventually appear in the fields. These are due partly to a rise in the water table and partly to an increase in the salt content of the surface soil. To insure permanent cultivation, it is necessary to supply drainage.

VARIATIONS FROM THE TYPICAL ASSOCIATION

Saltbush

In the Gila Valley the arrowweed and saltbush gives way to either areas where saltbush predominates or areas of pure saltbush, in which case the plants are large, luxuriant, and widely spaced (Pl. 12, A). These areas (fig. 3) are even less extensive than in Coachella Valley. They occupy similar situations—that is, the moister irregular areas along rivers or the abandoned fields where the water table is high. The texture of the soil is more like that of the mesquite thicket, having a higher moisture equivalent than that of any of the other types. As regards soil moisture, this land is wetter than mesquite thicket land since, at least in spring, the ground is wet to the surface and apt to be boggy. Even in October there is an abundance of water, in all 4 feet (Table XXV).

The physical conditions of land characterized by saltbush are (1) a soil that is uniform, at least 4 feet deep, and of fine texture; (2) a high water table; (3) an average salt content of ¾ per cent for the first foot, while the average for all 4 feet ranges from ½ to ¾ per cent.

SEEPWEED

TOPOGRAPHICAL CONDITIONS

Seepweed is widely distributed and grows well both in the Great Basin area and in the Southwestern desert region. In the Coachella Valley seepweed (*Dondia torreyana* (S. Wats. Standl.) forms a narrow and irregular belt on the more level land between the desert-sage and pickleweed land (fig. 2).

Seepweed grows in two quite distinct zones. One is on dry land, where it covers depressions of flat areas bordering *Atriplex linearis* S. Wats. or desert-sage. The other is on wet land (seepage land) bordering pickleweed or saltbush.

In the Gila Valley seepweed (*Dondia intermedia* (S. Wats.) Heller) occupies low flat areas that are poorly drained and are usually covered with water after a rain. This plant is quite frequent wherever the valley floor is a broad plain with very little slope. The pure areas are small, rarely exceeding 40 acres in extent, but are usually surrounded by larger areas mixed with either narrowleaf saltbush or a scrubby growth of desert-sage. These mixed areas are in turn surrounded by areas of pure narrowleaf saltbush or desert-sage. Seepweed also occurs in places where soil conditions and the associated plants are very different from those mentioned, namely, "seepage areas," where it is found with pickleweed, greasewood, saltgrass, or sporobolus. These are usually strips of land along streams, as the Gila River or the Little Gila, or below irrigated tracts of land.

TABLE XXV.—*Comparison of spring and fall soil conditions at the same station in a typical area of saltbush, Chandler, Ariz., 1915* [a]

Item	Depth of soil	Date of collection			Average	Date of collection			Average
		Mar. 26, sample No. 21	Mar. 27, sample No. 24	Mar. 17, sample No. 4		Oct. 5, sample No. 21	Oct. 5, sample No. 24	Oct. 5, sample No. 4	
	Feet								
Moisture equivalent	1	19.4	21.2	.....	20.3	20.5	21.4	.....	21.0
	2	18.9	20.9	.....	19.9	19.2	21.6	.....	20.4
	3	18.3	22.5	.....	20.4	19.7	21.1	.....	20.4
	4	22.9	23.3	.....	23.1	22.2	23.6	.....	22.9
Wilting coefficient	1	10.6	11.5	.....	11.1	11.1	11.6	.....	11.4
	2	10.3	11.4	.....	10.9	10.4	11.7	.....	11.1
	3	10.0	12.2	.....	11.1	10.7	11.5	.....	11.1
	4	12.5	12.7	.....	12.6	12.1	12.8	.....	12.5
Moisture content above or below wilting coefficient.	1	+14.7	+10.0	.....	+12.4	+7.4	+6.0	.....	+6.7
	2	+21.0	+15.9	.....	+18.5	+11.3	+8.5	.....	+9.9
	3	+25.0	+16.8	.....	+20.9	+13.1	+9.6	.....	+11.2
	4	+21.2	+18.2	.....	+19.7	+10.5	+11.8	.....	+11.2
Salt content	1	.45	.75	0.64	.61	.38	.97	1.34	.90
	2	.34	.41	.46	.40	1.48	.37	.47	.84
	3	.34	.38	.41	.38	.90	.32	.47	.56
	4	.33	.37	.....	.35	1.80	.31	.49	.87

[a] All data in this table are stated in percentages of the dry weight of the soil.

BOTANICAL COMPOSITION

Pure areas of seepweed, where no other plants are present are small and uncommon. In the Gila Valley plants of *Atriplex linearis* S. Wats., *Atriplex fasciculata* S. Wats., *Aster parviflorus* A. Gray, or, sometimes, *Plantago erecta* Morris are mixed with the seepweed (*Dondia intermedia* (S. Wats.) Heller.) However, when seep weed grows on the "seepage" lands it is mixed with *Allenrolfea occidentalis* (S. Wats.) Kuntze, *Sarcobatus vermiculatus* (Hook.) Torr., *Sporobolus airoides* Torr., *Distichlis spicata* (L.) Greene, *Atriplex lentiformis* (Torr.), S. Wats. and *Pluchea sericea* (Nutt.) Coville.

In Coachella Valley the seepweed (*Dondia torreyana* (S. Wats.) Standl.), outside of the small pure areas, mixes, on the one hand, with plants on wet saline land, as *Distichlis spicata* (L.) Greene, *Allenrolfea occidentalis* (S. Wats.) Kuntze, *Atriplex lentiformis* (Torr.) S. Wats. and *Fluchea sericea* (Nutt.) Coville, and, on the other hand, with plants on dry desert soil as *Atriplex polycarpa* (Torr.) S. Wats. and *Atriplex canescens* (Pursh) Nutt. In fact creosote bush (*Covillea glutinosa* (Engelm.) Rydb.) and the plant groups above the creosote bush area are the only ones with which Dondia does not mix. Where it is near Covillea, Dondia occupies depressions while Covillea grows on hummocks of lighter soil.

APPEARANCE

In the wet ("seep") areas, seepweed grows in dense tangled clumps with open spaces between the clumps, the soil being heavily crusted with salt (Pl. 14, A). In summer the plants are very dark green, but in late fall they are tinged with red or purple. Still later most of the leaves are dropped. The new growth comes on late in spring after the creosote bush has made most of its growth. This is probably due to the fact that there is much more moisture for the seepweed to draw on later in the season and also that, due to its location, the soil does not become warm as soon as in the case of the creosote bush land. Wherever seepweed areas are found on dry land the growth is usually not over 16 or 18 inches high, scant but quite uniform. In spring the plants are green but not as dark green as those on the wet areas. The plants on the dry land become tinged with red or purple earlier than those on the wet lands.

PHYSICAL CONDITIONS INDICATED

Soil Moisture

The texture of the soil indicated by the seepweed ranges from a fine sandy loam to a clay loam, usually somewhat heavier than that indicated by the desert-sage. The amount of available water is considerably greater than on desert-sage soil in the spring. In the fall the soil moisture of desert-sage land is considerably below the wilting coefficient, but the soil moisture of the seepweed land is somewhat above the wilting coefficient, at least in the third and fourth feet (Tables XXVI and XXVII). Where the seepweed grows on seep land there is usually abundant soil moisture all the year.

Salinity

Seepweed is a good indicator of saline land. The only exception to this is that seepweed may, as a weed, temporarily cover land once cultivated and then abandoned (Pl. 13, B), in which case it is not always an indicator of salinity (sample No. 44, Table XXVIII). Even when mixed with other plants it rarely fails as an indicator of high salt content of the soil (Table XXIX). In Tables XXVI, samples 11 and 12, and XXVII is shown the salt content on dry land. The first foot has a considerable salt content, at least in fall, while the last 3 feet are high in salt content. The salt content indicated by seepweed on "seep" land (Pl. 13, A) is shown in Table XXVIII, all 4 feet being high in salt content.

Summary of Physical Conditions

A rank tangled growth of seepweed indicates (1) a high water table; (2) a high salt content, the average of the 4 feet exceeding 1 per cent, while the first foot may contain over 2½ per cent (sample 13, Table XXVI).

A scant, low, uniform growth indicates (1) available water in all 4 feet in spring and usually some available water in the third and fourth feet in fall; (2) a high salt content, the average of the 4 feet ranging from ½ per cent to 1 per cent.

TABLE XXVI.—*Comparison of spring and fall soil conditions at the same stations in typical areas of seepweed, Indio, Calif., 1915* [a]

Item	Depth of soil	Date of collection			Average	Date of collection			Average
		Mar. 4, sample No. 11 [b]	Mar. 4, sample No. 12 [b]	Mar. 5, sample No. 13 [c]		Sept. 24, sample No. 11 [b]	Sept. 24, sample No. 12 [b]	Sept. 22, sample No. 13 [c]	
	Feet								
Moisture equivalent	1	11.6	25.8	33.0	23.5	18.6	27.7	35.0	27.1
	2	21.5	29.4	29.8	26.9	21.9	31.8	30.4	28.0
	3	4.9	25.0	32.2	20.7	11.6	17.7	30.0	19.8
	4	20.2	21.7	34.1	25.3	20.2	24.3	27.3	23.9
Wilting coefficient	1	6.3	14.0	17.9	12.7	10.1	15.1	19.0	14.7
	2	11.7	16.0	16.2	14.6	11.9	17.3	16.5	15.2
	3	2.7	13.6	17.5	11.3	6.3	9.6	16.3	10.7
	4	11.0	11.8	18.5	13.8	11.0	13.2	14.8	13.0
Moisture content above or below wilting coefficient.	1	+2.9	+7.2	+6.9	+5.7	−6.6	−13.7	−12.1	−10.8
	2	+7.4	+8.5	+8.7	+8.2	−0.8	−12.1	−4.3	−5.7
	3	+1.6	+1.0	+10.0	+4.2	+0.4	−3.8	+3.6	+0.1
	4	+0.3	−4.0	+10.5	+2.3	−1.3	−7.3	+10.3	+0.6
Salt content	1	.32	.16	>2.50	.99	.58	.18	>2.50	1.09
	2	.32	.60	1.16	.69	1.16	.94	1.04	1.05
	3	.66	.52	.32	.50	1.13	.67	1.04	.95
	4	1.58	.52	.26	.78	1.40	.58	.27	.75

[a] All data in this table are stated in percentages of the dry weight of the soil.
[b] Poor growth.
[c] Rank growth.

TABLE XXVII.—*A comparison of the spring and fall soil conditions at the same station on seepweed areas* [a]

Item	Depth of soil	Chandler, Ariz., 1915. Date of collection		Casa Grande, Ariz. Date of collection
		Mar. 25, sample No. 14 [b]	Oct. 7, sample No. 14 [b]	Oct. 11, 1915, sample No. 10 [b]
	Feet			
Moisture equivalent	1	5.4	5.5	16.0
	2	14.7	16.6	16.1
	3	14.9	20.2	16.0
	4	18.4	21.3	18.2
Wilting coefficient	1	2.9	3.0	8.7
	2	8.0	9.0	8.7
	3	8.1	11.0	8.7
	4	10.0	11.6	9.9
Moisture content above or below wilting coefficient	1	+1.9	−1.9	d [c]
	2	+5.6	−0.6	sm
	3	+4.0	+2.1	sm
	4	+6.1	+2.1	sm
Salt content	1	.02	.33	.25
	2	.14	.94	.50
	3	.54	1.16	1.04
	4	1.56	1.46	.70

[a] All data in this table are stated in percentages of the dry weight of the soil.
[b] Boring No. 14 was made in an area where seepweed was mixed with narrowleaf saltbush and mesquite. Boring No. 10 was made in a typical area of seepweed.
[c] d=dry soil; sm=slightly moist soil.

TABLE XXVIII.—*Soil conditions in September and October in typical areas of seepweed, Indio, Calif., 1914* [a]

Item	Depth of soil	Date of collection									Average
		Sept. 14, sample No. 13	Sept. 19, sample No. 26	Sept. 22, sample No. 27	Sept. 22, sample No. 31	Sept. 25, sample No. 44	Sept. 30, sample No. 54	Oct. 13, sample No. 76	Oct. 13, sample No. 78	Oct. 14, sample No. 84	
	Feet.										
Salt content	1	>2.50	>2.50	2.18	0.93	0.07	>2.50	2.30	0.76	0.23	1.55
	2	>2.50	2.10	1.13	1.18	.12	.20	1.60	1.04	1.36	1.23
	3	.38	1.22	1.56	1.36	.16	.11	.80	1.66	.64	.89
	4	.34	1.06	1.32	1.24	.20	.06	1.04	1.18	.52	.77
Water content	1	m [b]	m	d	d	d	w	d	d	d	.....
	2	m	m	m	m	d	w	d	sm	m	.....
	3	m	m	m	m	sm	w	sm	m	m	.....
	4	m	m	m	m	sm	w	sm	w	m	.....
Soil type	1	fl [c]	fsl	sl	s	fsl	fsl	fsl	sl	fsl	.....
	2	fl	fsl	sl	sl	fsl	sl	fsl	sl	fsl	.....
	3	l	fsl	sl	sl	fsl	sl	fsl	sl	sl	.....
	4	cl	fsl	sl	fsl	fsl	s	fsl	sl	s	.....

[a] No soil moisture or moisture equivalent determinations were made on the soil samples taken in 1914. The data given are the field notes on samples. Salt content data are stated in percentages of the dry weight of the soil.

[b] m=moist soil; sm=slightly moist soil; d=dry soil; w=wet soil.

[c] s=sand or sandy; l=loam; fsl=fine sandy loam; c=clay.

Seepweed land is excessively saline. In addition to this, one type of seepweed land also has a high water table. Both of these conditions must be corrected before this type of land can be profitably used for crop production. This land requires drainage first of all, for an attempt to leach out the salts by irrigating would make the land too boggy to be tillable.

ADAPTATIONS TO PHYSICAL CONDITIONS

Seepweed thrives best on land where available moisture is present all the year, at least in the third and fourth feet. On land at one time cultivated or on "seep" land the seepweed grows in tangled clumps, but on virgin desert soil the growth is much more sparse. Wherever the third and fourth feet become dry in summer the plants are very small and scattered, leaving open spaces of bare soil. The seepweed is dormant during the winter, and a large part of the plant above ground dies. The new leaves and branches begin to show about March. The root system is not extensive, but usually extends through the third and fourth feet of soil (Pl. 7,A).

VARIATIONS FROM THE TYPICAL ASSOCIATION

Seepweed with Desert-sage

This mixture, the most important one of those formed by seepweed, occurs generally on the lower edge of the desert-sage lands. In many of these areas neither the seepweed nor the desert-sage are at their best. The land is too dry during certain periods of the year for a good growth of seepweed, while the desert-sage finds the salt content too high for the best growth. The salt content (Table XXIX) is higher than that of the desert-sage land but lower than that of the seepweed land.

TABLE XXIX.—*Soil conditions in September and October in areas of seepweed mixed with other plants, Indio, Calif., 1914* [a]

Item	Depth of soil	Date of collection				Average	Date of collection								Average
		Sept. 23, sample No. 35, plant group D-Ap [b]	Oct. 2, sample No. 59, plant group D-Ap	Oct. 7, sample No. 64, plant group D-Ap	Oct. 13, sample No. 79, plant group D-Ap		Sept. 16, sample No. 20, plant group D-Ac	Sept. 19, sample No. 23, plant group D-Ac-Ap	Oct. 7, sample No. 67, plant group D-Ac-Ap	Oct. 14, sample No. 88, plant group D-P	Sept. 29, sample No. 51, plant group D-P	Oct. 1, sample No. 56, plant group D-P-Al	Oct. 15, sample No. 90, plant group D-Al	Oct. 14, sample No. 81, plant group D-I	Sept. 14, sample No. 10, plant group D-I	
Salt content	*Feet*														
	1	0.21	0.86	0.10	0.09	0.32	2.10	0.09	0.54	>2.50	2.30	>2.50	>2.50	1.10	1.40	1.67
	2	.20	.44	.07	.39	.28	0.56	.20	1.40	.24	.19	.80	.20	.72	.43	.64
	3	1.25	.26	.17	1.18	.72	1.32	.24	2.08	.17	.08	.24	.08	.80	.62	.61
	4	.67	.30	.17	.98	.53	.74	.23	.70	.14	.07	.18	.18	.72	.27	.35
Water content	1	d [c]	d	d	d	.....	nd	d	d	w	w	w	w	w	d	.....
	2	m	d	d	d	.....	sm	m	sm	w	w	w	w	w	sm	.....
	3	d	d	d	nd	.....	sm	m	m	w	w	w	w	w	m	.....
	4	m	d	d	nd	.....	sm	m	m	w	w	w	sa	w	m	.....
Soil type	1	s	fsl	fsl	sl	.....	fsl	s	s	fsl	sl	fsl	fsl	sl	l	.....
	2	fsl	s	fsl	sl	.....	fsl	s	s	fsl	sl	fsl	sl	sl	s	.....
	3	fsl	s	fsl	s	.....	l	s	s	sl	s	sl	sl	sl	s	.....
	4	fsl	s	fsl	fsl	.....	l	s	s	s	s	sl	sl	s	s	.....

[a] No soil moisture or moisture equivalent determinations were made on the 1914 soil samples. The data given are the field notes on the soil samples. Salt content data are stated in percentages of the dry weight of the soil

[b] D=*Dondia torreyana* (S. Wats.) Standl.; Ap=*Atriplex polycarpa* (Torr.) S. Wats.; Ac=*Atriplex canescens* (Pursh) Nutt.; I=*Isocoma veneta acradenia* (Greene) H. M. Hall; P=*Pluchea sericea* (Nutt.) Coville; Al=*Atriplex lentiformis* (Torr.) S. Wats.

[c] d=dry soil; m=moist soil; sm=slightly moist soil; nd=nearly dry soil; w=wet soil; sa=saturated soil; s=sand and sandy; l=loam; fsl=fine sandy loam.

Seepweed with Other Plants

Seepweed mixes with many other plants but these mixtures are of minor importance, covering only small areas. Table XXIX shows the salt content of the soil on which several of these mixtures occurred. The salt content is high wherever seepweed is found, with the exception of land formerly cultivated.

ATRIPLEX FASCICULATA

The land covered by *Atriplex fasciculata* S. Wats. is similar in appearance and texture of soil to the "bare flats" or "slick land" discussed under the next heading. In fact, it is merely that part of the bare flats, usually only the outer edges in the larger bare flats, where the soil conditions have been made more favorable by the rains, that this Atriplex springs up. The communities formed by *Atriplex fasciculata*, although small, are pure. Only at the outer borders do they mix with *Atriplex linearis* S. Wats. and scattered *Lycium parviflorum* A. Gray. *Atriplex fasciculata* S. Wats. appears as a small annual from 6 to 10 inches high. It is often dense enough to cover the ground completely. This plant springs up after the rains when there is water in the surface foot on the flats, grows rapidly and as the water is exhausted the plants mature. Where sample No. 5, Table XXX, was collected, there is a heavy layer of silt on the surface that hinders penetration. There was no available water here in the fall. Sample No. 11, Table XXX, shows a lighter soil, better penetration, and some available water in the fall in all the feet except the first.

The salt content is high (Table XXX) with an appreciable quantity even in the first foot.

TABLE XXX.—*A comparison of spring and fall soil conditions at the same station in a bare flat*[a]

Item	Depth of soil	Chandler, Ariz., 1915, date of collection		Casa Grande, Ariz., 1915, date of collection	
		Mar. 25, sample No. 15	Oct. 7, sample No. 15	Oct. 11, sample No. 5 [b]	Oct. 11, sample No. 11 [b]
	Feet				
Moisture equivalent	1	20.1	19.7	22.9	17.7
	2	18.9	18.6	19.2	17.5
	3	16.0	18.2	12.3	17.1
	4	15.9	19.2	12.0	17.9
Wilting coefficient	1	10.9	10.7	12.4	9.6
	2	10.3	10.1	10.4	9.5
	3	8.4	9.9	6.7	9.3
	4	9.0	10.4	6.5	9.7
Moisture content above or below wilting coefficient	1	−1.3	−4.4	[c] d	[c] d
	2	−0.5	0.0	d	sm
	3	+0.4	+1.2	d	sm
	4	+0.9	+2.9	d	sm
Salt content	1	2.12	2.68	.28	.34
	2	2.82	2.68	.48	1.00
	3	1.46	1.96	.32	.81
	4	1.00	1.58	.34	.31

[a] All data in percentages of the dry weight of the soil.
[b] Partly covered with an annual, *Atriplex fasciculata* S. Wats. No samples were taken here in spring.
[c] d=dry soil; sm=slightly moist soil.

BARE FLATS

Scattered throughout the mesquite thickets and occasionally in the lower places in the desert-sage areas in the Gila Valley there are curious spots sometimes an acre or two in extent called "slick land," "bare flats," or "playa flats" (Pl. 14, B). The first name applies to the slippery nature of the heavy soil when wet, as in spring. The name "bare flats" refers to the lack of vegetation on these spots. The dry lakes of the Mohave Desert and Death Valley region would also be included. In spring, or after a heavy rain, water stands on these bare flats for some time. The soil is very heavy and silty on the surface, and when dried cracks, leaving deep fissures in the soil. On the most typical of these no plants grow. Occasionally there are scattered, small plants of *Dondia intermedia* (S. Wats.) Heller, *Atriplex polycarpa* (Torr.) S. Wats., and *Lycium parviflorum* A. Gray. These plants occurred on small hummocks of lighter soil which stand a foot or more above the level of the flat. After rains a small annual, *Atriplex fasciculata* S. Wats., springs up on the more favorable portions of the flat. A single station was chosen in a bare flat and a boring made in the spring and in the fall. Soil moisture is present in the third and fourth feet, probably indicating the influence of a high water table. Of the samples collected the first two feet had no available water (Table XXX). The salt content is very high, ranging over 2 per cent in the first and second feet. More than one-half of the salt content is made up of chlorids (Table II, sample No. 11).

RELATIONS OF VEGETATION TO CLIMATIC CONDITIONS

The character of the vegetation in any region is an expression of the controlling factors of climate. The effect of moisture supply may be overcome or greatly altered by irrigation or by drainage. Temperature control is less likely to be locally interrupted except when there are abrupt variations in elevation. To express the temperature condition in a comparative way is very difficult, since summations are not yet possible, due largely to insufficient knowledge of plant physiology. We have not attempted the use of summation data, but have used the United States Weather Bureau summaries. These data are presented graphically in figures 7–9 and 14–21. In all cases the monthly values are plotted, beginning with January at the left. Rainfall is expressed in the usual way in figure 14. Below each graph is shown the mean annual rainfall, and the length of the record in years. The mean monthly temperature (fig. 15) is indicated by a bar and the lower extension drawn arbitrarily to 30 degrees below the annual mean value. This enables the reader to compare the different stations by a glance at the bottom of the mean monthly temperature graph. In figure 16 the absolute monthly maximum and the absolute monthly minimum are represented by the top and bottom of the light portion of the bars, while the mean monthly minimum and mean monthly maximum are represented by the bottom and the top of the shaded portion of the bar. On each graph are written the following annual values, the mean, the absolute maximum, the absolute minimum, the mean maximum and mean minimum, also the length of record in years, the type of vegetation, name of the station, and elevation above sea level.

The 41 stations shown in figure 14 are chosen to be fairly representative of the whole area of the southern desert, and of the types of vegetation considered in this paper. If we arrange these stations according to increasing rainfall, beginning with the lowest at the left, it is evident that the lowest rainfall occurs in those sections in which the vegetation is on the whole sparse and is composed either of creosote bush or desert-sage. All stations having a rainfall from 2 to 3½ inches are located in the Colorado desert of California. For the most part this rainfall occurs in late summer and there is little rain in early summer.

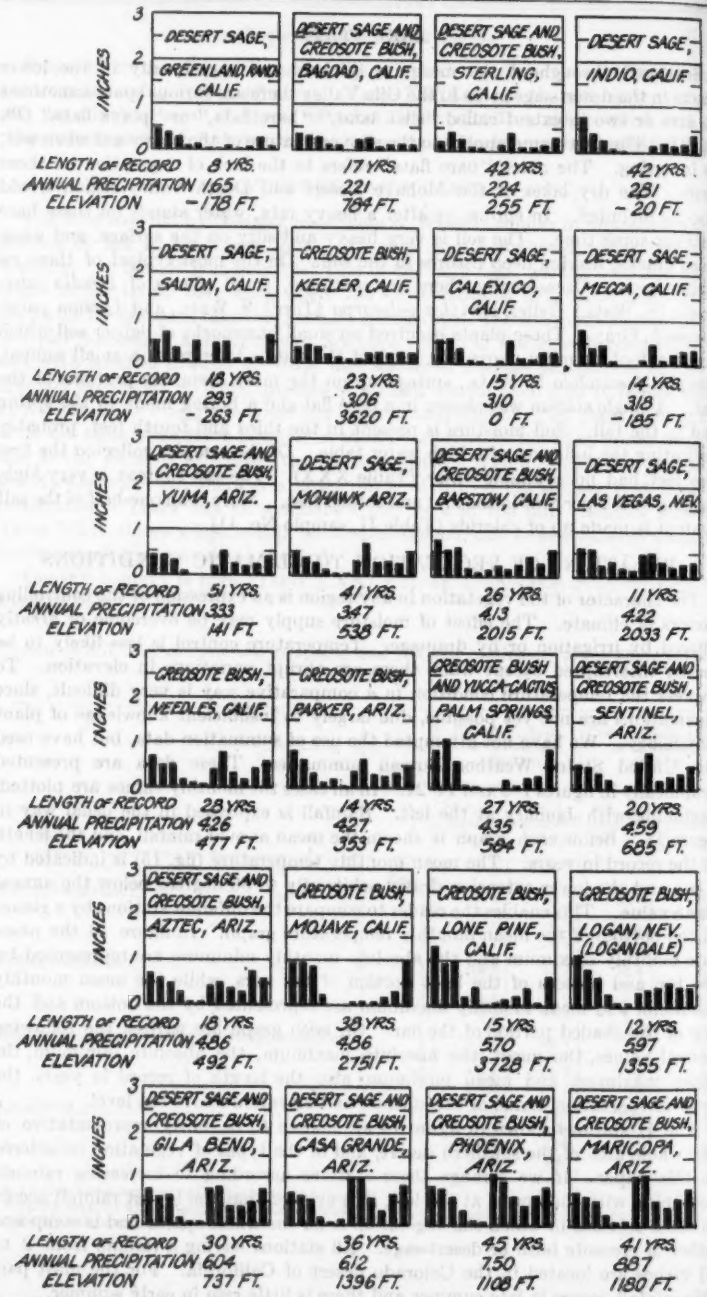
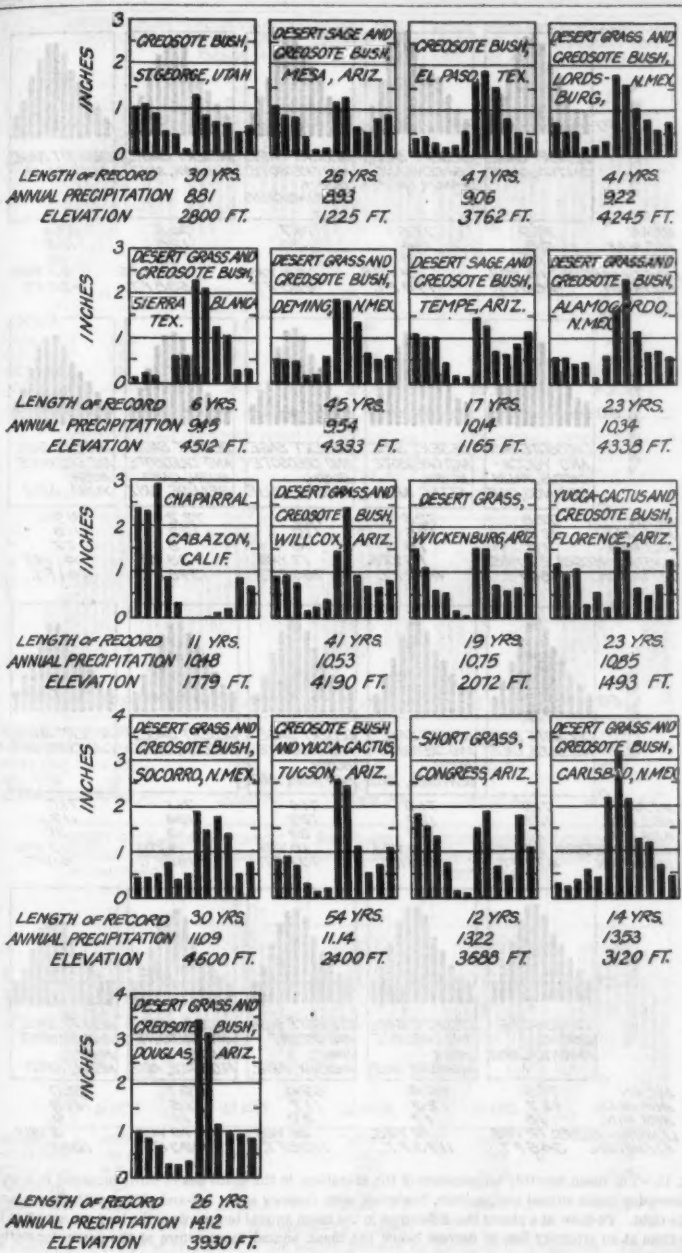

INCHES
3
2
1
0
DESERT SAGE, GREENLAND, AND CALIF.
DESERT SAGE AND CREOSOTE BUSH, BAGDAD, CALIF.
DESERT SAGE AND CREOSOTE BUSH, STERLING, CALIF.
DESERT SAGE, INDIO, CALIF.
LENGTH OF RECORD 8 YRS. 17 YRS. 42 YRS. 42 YRS.
ANNUAL PRECIPITATION 165 221 224 281
ELEVATION -178 FT. 784 FT. 255 FT. -20 FT.
DESERT SAGE, SALTON, CALIF.
CREOSOTE BUSH, KEELER, CALIF.
DESERT SAGE, CALEXICO, CALIF.
DESERT SAGE, MECCA, CALIF.
LENGTH OF RECORD 18 YRS. 23 YRS. 15 YRS. 14 YRS.
ANNUAL PRECIPITATION 293 306 310 318
ELEVATION -263 FT. 3620 FT. 0 FT. -185 FT.
DESERT SAGE AND CREOSOTE BUSH, YUMA, ARIZ.
DESERT SAGE, MOHAWK, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, BARSTOW, CALIF.
DESERT SAGE, LAS VEGAS, NEV.
LENGTH OF RECORD 51 YRS. 41 YRS. 26 YRS. 11 YRS.
ANNUAL PRECIPITATION 333 347 413 422
ELEVATION 141 FT. 538 FT. 2015 FT. 2033 FT.
CREOSOTE BUSH, NEEDLES, CALIF.
CREOSOTE BUSH, PARKER, ARIZ.
CREOSOTE BUSH AND YUCCA-CACTUS, PALM SPRINGS, CALIF.
DESERT SAGE AND CREOSOTE BUSH, SENTINEL, ARIZ.
LENGTH OF RECORD 28 YRS. 14 YRS. 27 YRS. 20 YRS.
ANNUAL PRECIPITATION 426 427 435 459
ELEVATION 477 FT. 353 FT. 584 FT. 685 FT.
DESERT SAGE AND CREOSOTE BUSH, AZTEC, ARIZ.
CREOSOTE BUSH, MOJAVE, CALIF.
CREOSOTE BUSH, LONE PINE, CALIF.
CREOSOTE BUSH, LOGAN, NEV. (LOGANDALE)
LENGTH OF RECORD 18 YRS. 38 YRS. 15 YRS. 12 YRS.
ANNUAL PRECIPITATION 486 486 570 597
ELEVATION 492 FT. 2751 FT. 3728 FT. 1355 FT.
DESERT SAGE AND CREOSOTE BUSH, GILA BEND, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, CASA GRANDE, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, PHOENIX, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, MARICOPA, ARIZ.
LENGTH OF RECORD 30 YRS. 36 YRS. 45 YRS. 41 YRS.
ANNUAL PRECIPITATION 604 612 750 687
ELEVATION 737 FT. 1396 FT. 1108 FT. 1180 FT.

FIG. 14.—Monthly rainfall at 41 stations in the south desert shrub, arranged in order of increasing mean annual rainfall. The January rainfall is given in inches at the left of each small graph and the December


INCHES
CREOSOTE BUSH, ST. GEORGE, UTAH
DESERT SAGE AND CREOSOTE BUSH, MESA, ARIZ.
CREOSOTE BUSH, EL PASO, TEX.
DESERT GRASS AND CREOSOTE BUSH, LORDSBURG, N.MEX.
LENGTH OF RECORD 30 YRS. 26 YRS. 47 YRS. 41 YRS.
ANNUAL PRECIPITATION 8.81 8.93 9.06 9.22
ELEVATION 2800 FT. 1225 FT. 3762 FT. 4245 FT.
INCHES
DESERT GRASS AND CREOSOTE BUSH, SIERRA BLANCA TEX.
DESERT GRASS AND CREOSOTE BUSH, DEMING, N.MEX.
DESERT SAGE AND CREOSOTE BUSH, TEMPE, ARIZ.
DESERT GRASS AND CREOSOTE BUSH, ALAMOGORDO, N.MEX.
LENGTH OF RECORD 6 YRS. 45 YRS. 17 YRS. 23 YRS.
ANNUAL PRECIPITATION 9.45 9.54 10.14 10.34
ELEVATION 4512 FT. 4333 FT. 1165 FT. 4338 FT.
INCHES
CHAPARRAL, CABAZON, CALIF.
DESERT GRASS AND CREOSOTE BUSH, WILLCOX, ARIZ.
DESERT GRASS, WICKENBURG, ARIZ.
YUCCA-CACTUS AND CREOSOTE BUSH, FLORENCE, ARIZ.
LENGTH OF RECORD 11 YRS. 41 YRS. 19 YRS. 23 YRS.
ANNUAL PRECIPITATION 10.48 10.53 10.75 10.85
ELEVATION 1779 FT. 4190 FT. 2072 FT. 1493 FT.
INCHES
DESERT GRASS AND CREOSOTE BUSH, SOCORRO, N.MEX.
CREOSOTE BUSH AND YUCCA-CACTUS, TUCSON, ARIZ.
SHORT GRASS, CONGRESS, ARIZ.
DESERT GRASS AND CREOSOTE BUSH, CARLSBAD, N.MEX.
LENGTH OF RECORD 30 YRS. 54 YRS. 12 YRS. 14 YRS.
ANNUAL PRECIPITATION 11.09 11.14 13.22 13.53
ELEVATION 4600 FT. 2400 FT. 3688 FT. 3120 FT.
INCHES
DESERT GRASS AND CREOSOTE BUSH, DOUGLAS, ARIZ.
LENGTH OF RECORD 26 YRS.
ANNUAL PRECIPITATION 14.12
ELEVATION 3930 FT.

[Figure 14—Continued]

rainfall at the right. A prominent type of vegetation which occurs at the station and the name of the station are shown above the graph. Below it are given the mean annual precipitation, the length of the rainfall record in years, and the elevation above sea level.

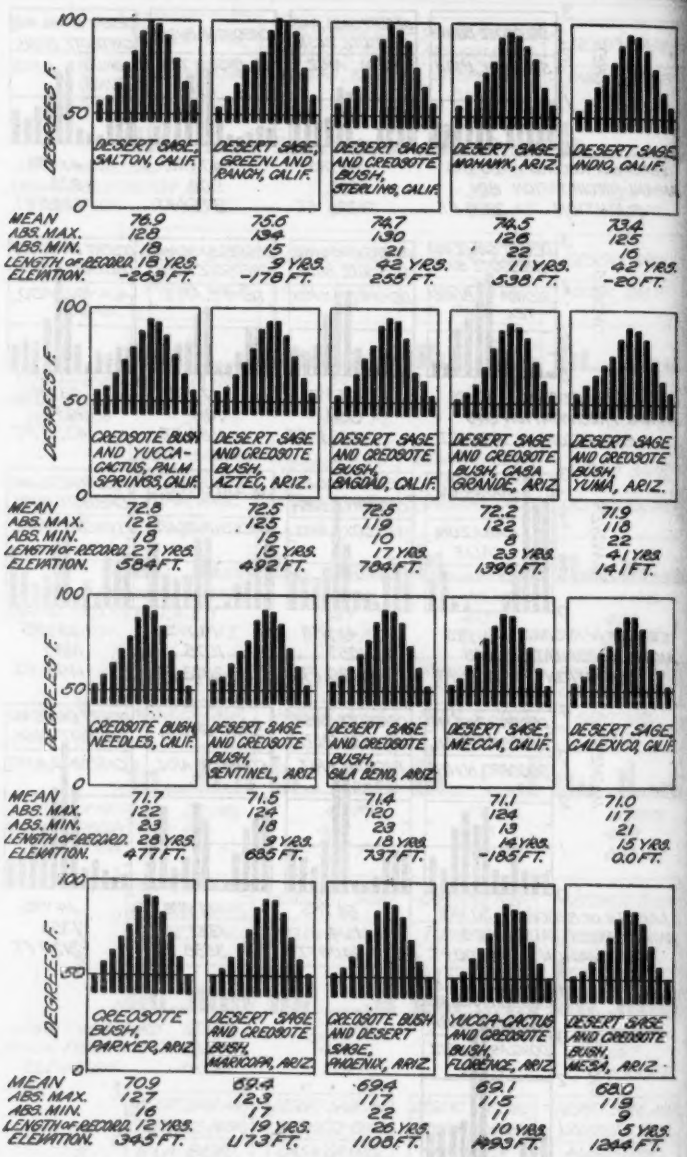

100
50
0
DEGREES F.
DESERT SAGE, SALTON, CALIF.
DESERT SAGE, GREENLAND RANCH, CALIF.
DESERT SAGE AND CREOSOTE BUSH, STERLING, CALIF.
DESERT SAGE, MOHAVE, ARIZ.
DESERT SAGE, INDIO, CALIF.
MEAN 76.9 75.6 74.7 74.5 73.4
ABS. MAX. 128 134 130 126 125
ABS. MIN. 18 15 21 22 16
LENGTH OF RECORD 18 YRS. 9 YRS. 42 YRS. 11 YRS. 42 YRS.
ELEVATION. -269 FT. -178 FT. 255 FT. 538 FT. -20 FT.
CREOSOTE BUSH AND YUCCA-CACTUS, PALM SPRINGS, CALIF.
DESERT SAGE AND CREOSOTE BUSH, AZTEC, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, BAGDAD, CALIF.
DESERT SAGE AND CREOSOTE BUSH, CASA GRANDE, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, YUMA, ARIZ.
MEAN 72.8 72.5 72.5 72.2 71.9
ABS. MAX. 122 125 119 122 118
ABS. MIN. 18 15 10 8 22
LENGTH OF RECORD 27 YRS. 15 YRS. 17 YRS. 23 YRS. 41 YRS.
ELEVATION. 584 FT. 492 FT. 784 FT. 1396 FT. 141 FT.
CREOSOTE BUSH, NEEDLES, CALIF.
DESERT SAGE AND CREOSOTE BUSH, SENTINEL, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, GILA BEND, ARIZ.
DESERT SAGE, MECCA, CALIF.
DESERT SAGE, CALEXICO, CALIF.
MEAN 71.7 71.5 71.4 71.1 71.0
ABS. MAX. 122 124 120 124 117
ABS. MIN. 23 18 23 13 21
LENGTH OF RECORD 28 YRS. 9 YRS. 18 YRS. 14 YRS. 15 YRS.
ELEVATION. 477 FT. 685 FT. 737 FT. -185 FT. 0.0 FT.
CREOSOTE BUSH, PARKER, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, MARICOPA, ARIZ.
CREOSOTE BUSH AND DESERT SAGE, PHOENIX, ARIZ.
YUCCA-CACTUS AND CREOSOTE BUSH, FLORENCE, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, MESA, ARIZ.
MEAN 70.9 69.4 69.4 69.1 68.0
ABS. MAX. 127 123 117 115 113
ABS. MIN. 16 17 22 11 9
LENGTH OF RECORD 12 YRS. 19 YRS. 26 YRS. 10 YRS. 5 YRS.
ELEVATION. 345 FT. 1173 FT. 1106 FT. 1493 FT. 1244 FT.

FIG. 15.—The mean monthly temperature of the 40 stations in the south desert shrub arranged in order of decreasing mean annual temperature, beginning with January at the left and ending with December at the right. To show at a glance the differences in the mean annual temperature the bars are cut off at the bottom at an arbitrary line 30 degrees below the mean annual temperature of the particular station.

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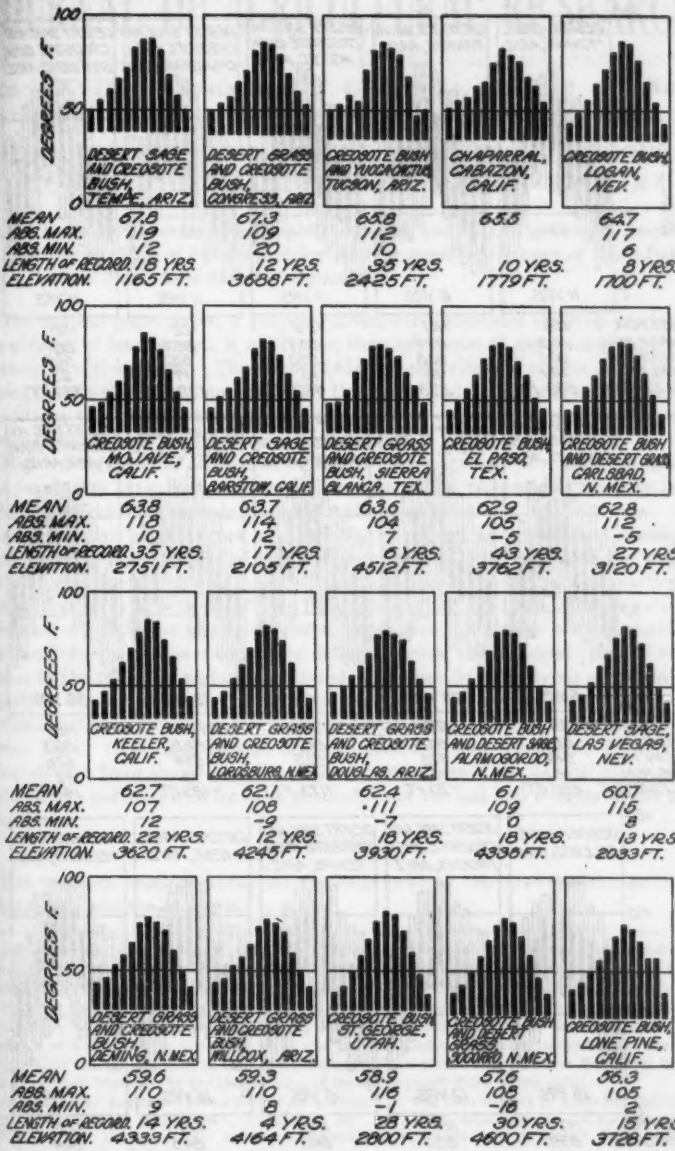

DEGREES F.
100
50
0
DESERT SAGE AND CREOSOTE BUSH, TEMPE, ARIZ.
DESERT GRASS AND CREOSOTE BUSH, CONGRESS, ARIZ.
CREOSOTE BUSH AND YUCCA ORCUTTII, TUCSON, ARIZ.
CHAPARRAL, CABAZON, CALIF.
CREOSOTE BUSH, LOGAN, NEV.
MEAN 67.8 67.3 65.8 65.5 64.7
ABS. MAX. 119 109 112 117
ABS. MIN. 12 20 10 6
LENGTH OF RECORD 18 YRS. 12 YRS. 35 YRS. 10 YRS. 8 YRS.
ELEVATION. 1165 FT. 3688 FT. 2425 FT. 1779 FT. 1700 FT.
DEGREES F.
100
50
0
CREOSOTE BUSH, MOJAVE, CALIF.
DESERT SAGE AND CREOSOTE BUSH, BARSTOW, CALIF.
DESERT GRASS AND CREOSOTE BUSH, SIERRA BLANCA, TEX.
CREOSOTE BUSH, EL PASO, TEX.
CREOSOTE BUSH AND DESERT GRASS, CARLSBAD, N. MEX.
MEAN 63.8 63.7 63.6 62.9 62.8
ABS. MAX. 118 114 104 105 112
ABS. MIN. 10 12 7 -5 -5
LENGTH OF RECORD 35 YRS. 17 YRS. 6 YRS. 43 YRS. 27 YRS.
ELEVATION. 2751 FT. 2105 FT. 4512 FT. 3762 FT. 3120 FT.
DEGREES F.
100
50
0
CREOSOTE BUSH, KEELER, CALIF.
DESERT GRASS AND CREOSOTE BUSH, LORDSBURG, N. MEX.
DESERT GRASS AND CREOSOTE BUSH, DOUGLAS, ARIZ.
CREOSOTE BUSH AND DESERT SAGE, ALAMOGORDO, N. MEX.
DESERT SAGE, LAS VEGAS, NEV.
MEAN 62.7 62.1 62.4 61 60.7
ABS. MAX. 107 108 111 109 115
ABS. MIN. 12 -9 -7 0 8
LENGTH OF RECORD 22 YRS. 12 YRS. 18 YRS. 18 YRS. 13 YRS.
ELEVATION. 3620 FT. 4245 FT. 3930 FT. 4336 FT. 2033 FT.
DEGREES F.
100
50
0
DESERT GRASS AND CREOSOTE BUSH, DEMING, N. MEX.
DESERT GRASS AND CREOSOTE BUSH, WILLCOX, ARIZ.
CREOSOTE BUSH, ST. GEORGE, UTAH.
CREOSOTE BUSH AND DESERT GRASS, JOGARD, N. MEX.
CREOSOTE BUSH, LONE PINE, CALIF.
MEAN 59.6 59.3 58.9 57.6 56.3
ABS. MAX. 110 110 116 108 105
ABS. MIN. 9 8 -1 -16 2
LENGTH OF RECORD 14 YRS. 4 YRS. 28 YRS. 30 YRS. 15 YRS.
ELEVATION. 4333 FT. 4164 FT. 2800 FT. 4600 FT. 3728 FT.

[Figure 15—Continued]

In each graph are shown the type of vegetation and the station. Below in figures are given the mean, absolute maximum and absolute minimum temperatures, the length of the record in years and the elevation.

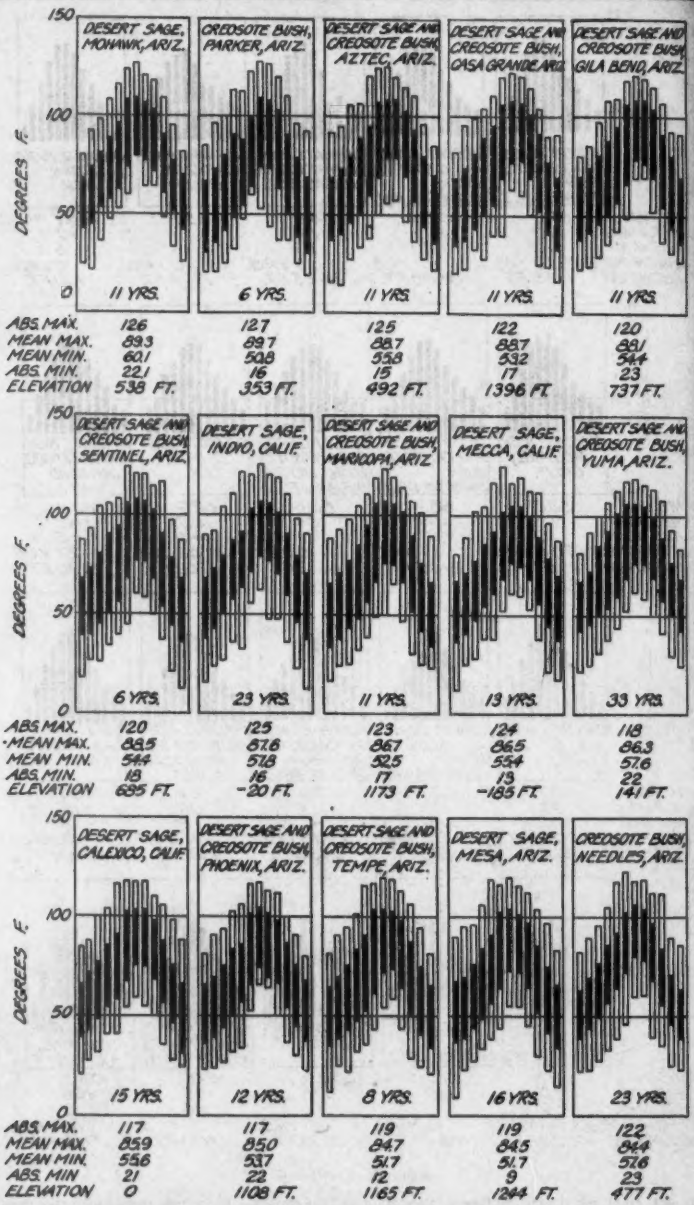
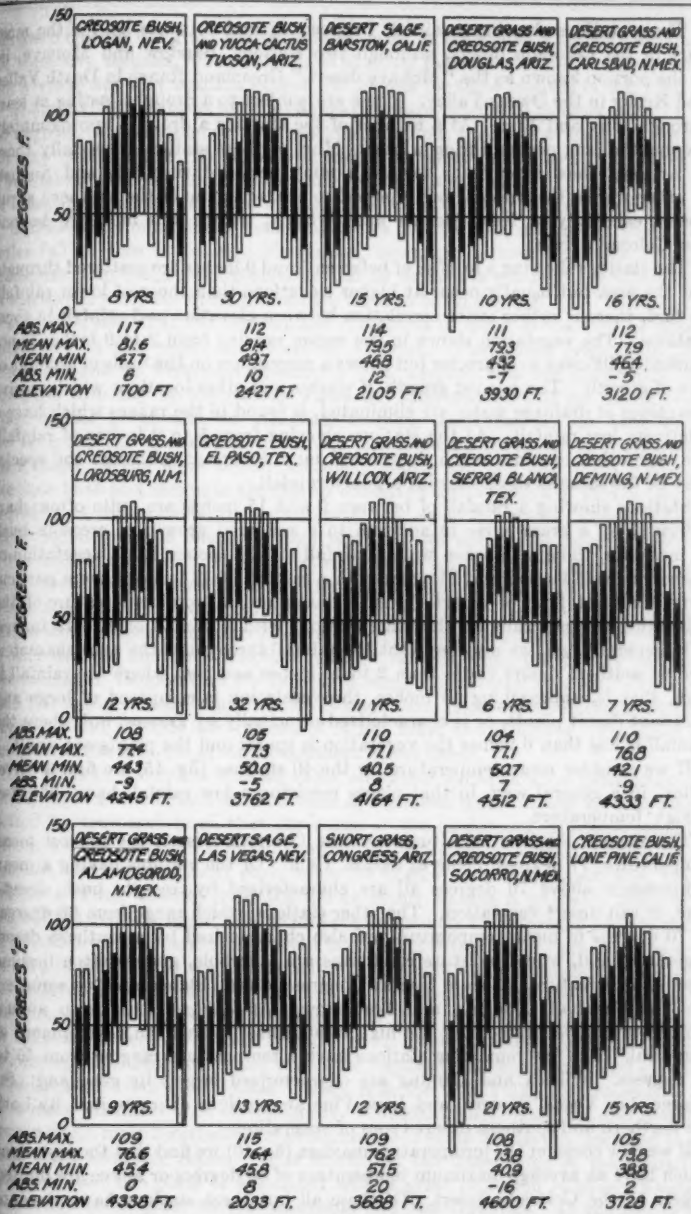

DESERT SAGE, MOHAWK, ARIZ.
CREOSOTE BUSH, PARKER, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, AZTEC, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, CASA GRANDE, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, GILA BEND, ARIZ.
DEGREES F.
150
100
50
0
11 YRS.
6 YRS.
11 YRS.
11 YRS.
11 YRS.
ABS. MAX. 126 127 125 122 120
MEAN MAX. 89.3 89.7 88.7 88.7 88.1
MEAN MIN. 60.1 50.8 35.8 33.2 34.4
ABS. MIN. 22.1 16 15 17 23
ELEVATION 538 FT. 353 FT. 492 FT. 1396 FT. 737 FT.
DESERT SAGE AND CREOSOTE BUSH, SENTINEL, ARIZ.
DESERT SAGE, INDIO, CALIF.
DESERT SAGE AND CREOSOTE BUSH, MARICOPA, ARIZ.
DESERT SAGE, MECCA, CALIF.
DESERT SAGE AND CREOSOTE BUSH, YUMA, ARIZ.
DEGREES F.
150
100
50
0
6 YRS.
23 YRS.
11 YRS.
13 YRS.
33 YRS.
ABS. MAX. 120 125 123 124 118
MEAN MAX. 88.5 87.6 86.7 86.5 86.3
MEAN MIN. 54.4 51.8 52.5 55.4 57.6
ABS. MIN. 18 16 17 13 22
ELEVATION 695 FT. -20 FT. 1173 FT. -185 FT. 141 FT.
DESERT SAGE, CALEXICO, CALIF.
DESERT SAGE AND CREOSOTE BUSH, PHOENIX, ARIZ.
DESERT SAGE AND CREOSOTE BUSH, TEMPE, ARIZ.
DESERT SAGE, MESA, ARIZ.
CREOSOTE BUSH, NEEDLES, ARIZ.
DEGREES F.
150
100
50
0
15 YRS.
12 YRS.
8 YRS.
16 YRS.
23 YRS.
ABS. MAX. 117 117 119 119 122
MEAN MAX. 85.9 85.0 84.7 84.5 84.4
MEAN MIN. 55.6 53.7 51.7 51.7 57.6
ABS. MIN 21 22 12 9 23
ELEVATION 0 1108 FT. 1165 FT. 1244 FT. 477 FT.

FIG. 16.—The monthly absolute maximum, absolute minimum, mean maximum, and mean minimum temperatures of 30 stations arranged in order of decreasing mean annual temperature. The absolute maximum and minimum for each month are shown by the upper and lower end of the light portion of the bar. The mean maximum and minimum by the upper and lower end of the shaded portion. The values for January are shown at the left, ending with December at the right. At the top within the graph is given


DEGREES F.
150
100
50
0
CREOSOTE BUSH, LOGAN, N.EV.
8 YRS.
CREOSOTE BUSH, AND YUCCA-CACTUS TUCSON, ARIZ.
30 YRS.
DESERT SAGE, BARSTOW, CALIF.
15 YRS.
DESERT GRASS AND CREOSOTE BUSH, DOUGLAS, ARIZ.
10 YRS.
DESERT GRASS AND CREOSOTE BUSH, CARLSBAD, N.MEX.
16 YRS.
ABS. MAX. 117 112 114 111 112
MEAN MAX. 81.6 84 79.5 79.3 77.9
MEAN MIN. 41.7 49.7 46.8 43.2 46.4
ABS. MIN. 6 10 12 -7 -5
ELEVATION 1700 FT. 2427 FT. 2105 FT. 3930 FT. 3120 FT.
DEGREES F.
150
100
50
0
DESERT GRASS AND CREOSOTE BUSH, LORDSBURG, N.M.
12 YRS.
CREOSOTE BUSH, EL PASO, TEX.
32 YRS.
DESERT GRASS AND CREOSOTE BUSH, WILLCOX, ARIZ.
11 YRS.
DESERT GRASS AND CREOSOTE BUSH, SIERRA BLANCA, TEX.
6 YRS.
DESERT GRASS AND CREOSOTE BUSH, DEMING, N.MEX.
7 YRS.
ABS. MAX. 108 105 110 104 110
MEAN MAX. 77.4 77.3 77.1 77.1 76.8
MEAN MIN. 44.3 50.0 40.5 50.7 42.1
ABS. MIN. -9 -5 8 7 9
ELEVATION 4245 FT. 3762 FT. 4164 FT. 4512 FT. 4333 FT.
DEGREES F.
150
100
50
0
DESERT GRASS AND CREOSOTE BUSH, ALAMOGORDO, N.MEX.
9 YRS.
DESERT SAGE, LAS VEGAS, NEV.
13 YRS.
SHORT GRASS, CONGRESS, ARIZ.
12 YRS.
DESERT GRASS AND CREOSOTE BUSH, SOCORRO, N.MEX.
21 YRS.
CREOSOTE BUSH, LONE PINE, CALIF.
15 YRS.
ABS. MAX. 109 115 109 108 105
MEAN MAX. 76.6 76.4 76.2 73.8 73.8
MEAN MIN. 45.4 45.8 51.5 40.9 38.8
ABS. MIN. 0 8 20 -16 2
ELEVATION 4338 FT. 2033 FT. 3688 FT. 4600 FT. 3728 FT.

[Figure 16—Continued]

the predominating type of vegetation at the station followed by the name of the station. The period of years covered by the temperature records is written within the graph at the bottom. Below each graph are given the absolute maximum, mean maximum, mean minimum, and absolute minimum temperatures, and the elevation of the station in feet.

Those stations showing a rainfall between 3½ and 5 inches lie, for the most part in the Colorado desert, although two stations, Barstow and Mohave, lie in the portion known as the "Mohave desert," Greenland Ranch in Death Valley and Keeler in the Owens Valley. These are subject to a drought lasting at least through May and June. At a number of the stations a drought approximately six months long occurs during winter. Most of these stations, especially those in Arizona, show a tendency toward a rainy period during July and August; in other words, the summer rainy period so characteristic of the southern shrub desert, especially of New Mexico and Arizona, carries this influence beyond the Colorado river.

The stations showing a rainfall of between 5 and 9 inches are scattered throughout the area but usually occur at higher elevations than those of lower rainfall. In fact, there is rather strict correlation between elevation and rainfall in these stations. The vegetation shown in the region ranging from 2 to 9 inches is not markedly different in character but shows a correlation on the basis of amount or size of growth. The poorest growth, if washes and other locations which receive quantities of drainage water are eliminated, is found in the ranges which have a relatively low rainfall. At the stations showing from 5 to 9 inches of rainfall, the vegetation becomes much denser and more luxuriant, although the species may be the same as those showing a 2-inch rainfall.

Stations showing a rainfall of between 9 and 15 inches are quite often characterized by a grass cover in addition to a scattered growth of creosote bush or mesquite, though Cabazon with a rainfall of 10½ inches has a vegetation of chaparral, and Tucson and Florence with a rainfall of 12 inches have a particularly luxuriant type of desert shrub. Grasses are a prominent feature of the vegetation at practically all the other stations with a rainfall of 9 to 15 inches.

In general, then, we may say that the rainfall throughout the area characterized as southern desert varies from 2 to 15 inches and that where the rainfall is high, that is, approaching 15 inches, the vegetation is composed of large and luxuriant desert plants, or is characterized principally by grasses, but where the rainfall is less than 6 inches the vegetation is sparse and the plants are small.

If we consider mean temperature for the 40 stations (fig. 15) we find a correlation, in a general way, in that places receiving a low rainfall have, likewise, a high temperature.

The warmer stations are situated in the Colorado desert, the highest mean temperature, 77 degrees, being at Salton, Calif. Of the stations having a mean temperature above 70 degrees all are characterized by creosote bush, desert-sage, or salt desert vegetation. The other stations, which range from 60 degrees to 70 degrees in mean temperature are also characterized by a southern desert vegetation and, where moisture conditions are favorable, grasses often become a prominent feature. This is true at Congress, Sierra Blanca and, to some extent, at Carlsbad, Douglas, and Lordsburg. At Cabazon the mean annual temperature is 65 degrees but the high rainfall has favored the development of chaparral. The few remaining stations have a temperature ranging from 56 to 60 degrees. Willcox and Deming are characterized largely by grassland; St. George, Las Vegas, Socorro, and Lone Pine are stations characterized by both the northern and southern desert types of vegetation.

If we now consider the termperature maxima (fig. 16) we find that those stations which have an average maximum temperature of 85 degrees or above are limited largely to the Colorado desert. Of these all but three stations have absolute maxima of 120 degrees or above and four above 125 degrees. The monthly mean maximum is above 100 degrees for the four months, June, July, August, and September at nine of the stations considered. The stations having annual mean maximum temperatures between 80 degrees and 85 degrees either lie near the

northern edge of the great southern desert area, or they have a higher elevation. Of these five stations, all but one have absolute maxima above 115 degrees and the average monthly maxima exceed 100 degrees for three months in the year.

The remaining stations have an annual average maximum ranging from 74 to 80 degrees. In only one of these stations, Barstow, does the average maximum for any month reach 100 degrees, in fact only rarely does it reach 95 degrees. The highest absolute maximum in this region, 114 degrees, is at Barstow. All of these stations have recorded maximum temperatures of 100 degrees or more.

Considering the minimum temperature we find only six stations in the whole series fall to zero or below. No station, however, is frost free. An average minimum temperature of between 50 and 60 degrees is recorded for about half of the series, while the other half ranges from 39 to 50 degrees.

It is thus seen that the temperature conditions in much of the type of desert considered in this paper are relatively extreme. The plants growing in this desert are able to withstand excessively high temperatures but apparently can not push into any of the regions where the temperature falls far below zero. They appear to be able to withstand freezing temperatures, but even these low temperatures undoubtedly do much to change the character of the growth, since many of the more tender succulent plants can not well resist freezing. Creosote bush and mesquite are able to withstand temperatures of zero or below, provided, of course, these temperatures do not occur too often. Creosote bush and mesquite require relatively high temperatures during the growing period.

We may summarize briefly the extreme record for this desert type of vegetation. Desert-sage occurs in regions having a range of rainfall of from 2 to 12 inches and doubtless would flourish with a much higher rainfall. The average temperature ranges from 56 to 77 degrees, with average maxima ranging from 73 to 90.7 degrees and with absolute maxima ranging from 109 to 134 degrees. The minimum temperature for this plant ranges practically to zero. Creosote bush has a wider range than the desert-sage, since it occupies somewhat higher elevations and extends into regions of rather lower temperatures. Its range is the same as the total range for the southern desert shrub.

The areas in which the Yuccas, cacti, and other succulents are prominent do not include the hotter and drier stations of the lower land. These are also more limited by temperature so that the range of the succulents expressed roughly is from 4 to 12 inches in rainfall, from 63 to 73 degrees in average annual temperature, and, for the most part, below 85 degrees in average maximum temperature. Their absence from the hotter desert regions is probably more the result of the distribution of rainfall and the excessively long drought periods than the actual lower temperatures, since it is doubtful if the higher temperatures are effective in eliminating the succulents, if the distribution of rainfall is favorable

A selected series of stations may now be considered in relation to vegetation and temperature and rainfall conditions (fig. 17). In passing eastward across the southern desert shrub, the conditions for growth become more favorable. Barstow is in the Mohave desert, where the vegetation is very sparse, and mostly of the creosote bush type. Casa Grande is in the Gila Valley and represents a much more luxuriant type of vegetation. Creosote bush, mesquite, and desert-sage are much more luxuriant than at Barstow. Tucson lies farther east and in a much more favorable region. It is located at the upper edge of the creosote bush zone and this plant is associated with a great profusion of desert forms, such as mesquite, giant cactus, paloverde and the Opuntias. It represents a luxuriant type of pure desert shrub. As one passes from Barstow to Tuscon, the rainfall increases and the vegetation becomes more luxuriant. Barstow has a dry summer, from April to October, while both Casa Grande and Tucson have a drought period of only three months, April to June, inclusive.

As a result of this difference, Casa Grande and Tucson show a relatively great development of summer annuals. It seems probable that if the rainfall during August and September were increased somewhat, both places would develop a grass cover. Lordsburg is in a grass country with creosote bush a prominent plant. The grasses of the mesquite-grass type grow during the summer rainy period. The distribution of rainfall from July to December is similar to the Great Plains type, in a region intermediate between grassland and desert shrub. Lordsburg is somewhat cooler than the other stations considered, but moisture conditions chiefly are important in explaining this change in vegetation. Big Springs has the temperature required for the southern desert shrub and the rainfall sufficient to develop a grass cover. As a result, we have mesquite scattered over a mesquite-grass type. The range of temperature is a little greater at Big Springs and Lordsburg than at the other stations.

A similar series, but one which introduces temperature changes of significance, is shown in figure 18. Mohawk is located low in the Gila Valley. The temperature is very high, the mean annual being 74.5 degrees and the mean being above 90 degrees for three months of the year. During June, July, and August the mean maximum ranges from 105 degrees to 110 degrees and the absolute maximum reaches more than 100 degrees for seven of the twelve months of the year. The lowest temperature recorded is 22° F. Passing northeastward to Phoenix the rainfall becomes twice as heavy. Except for the more luxuriant growth, there is comparatively little change in vegetation. Creosote bush and desert-sage are the prominent types. The temperature is somewhat lower at Phoenix, but not low enough to eliminate any important element from the vegetation. At Socorro a marked change is noted in the vegetation. Creosote bush is near its limit, while the mesquite grassland and Yucca are prominent. Temperature falls to −16 degrees and the average is approximately 18 degrees lower than at Mohawk. The great change of temperature does not prevent the occurrence of mesquite and creosote bush. The rainfall is similar to Lordsburg, that is, of the Great Plains type, from July to November. Amarillo is in pure short-grass country. The average temperature is only a little lower than at Socorro. The summer rainfall is typical of the Great Plains and sufficient to develop a pure short-grass cover.

In this series, temperatures at Socorro and Amarillo are probably a little too low for the desert-shrub type, while the distribution of rainfall favors a grass cover. The short-grass cover would probably give way to mesquite grass if temperatures were as high at Amarillo as at Lordsburg or Big Springs, while Socorro would probably have the short-grass type instead of mesquite grass if the distribution of rainfall were similar to Amarillo.

A similar series selected in Arizona (fig. 19) shows a change from the luxuriant creosote bush type at Maricopa to the short grassland at Congress and to yellow pine at Williams. These changes are accompanied by temperature and precipitation differences. Maricopa and Congress do not show marked difference in temperature means, but Maricopa has a much higher summer maximum. Rainfall is twice as heavy at Congress as at Maricopa. This high rainfall favors the development of short-grass at Congress, while at Maricopa the grasses do not develop. At Williams, where the yellow pine is the dominant type, the rainfall is three times as heavy as at Maricopa, and the mean temperature about 20 degrees lower.

Minimum temperatures below zero are recorded only at Williams, and these low temperatures—the summer maximum seldom reaches 100 degrees—are in sharp contrast to Maricopa, where during four months of the year the average maximum exceeds 100 degrees and where zero temperatures are never recorded.

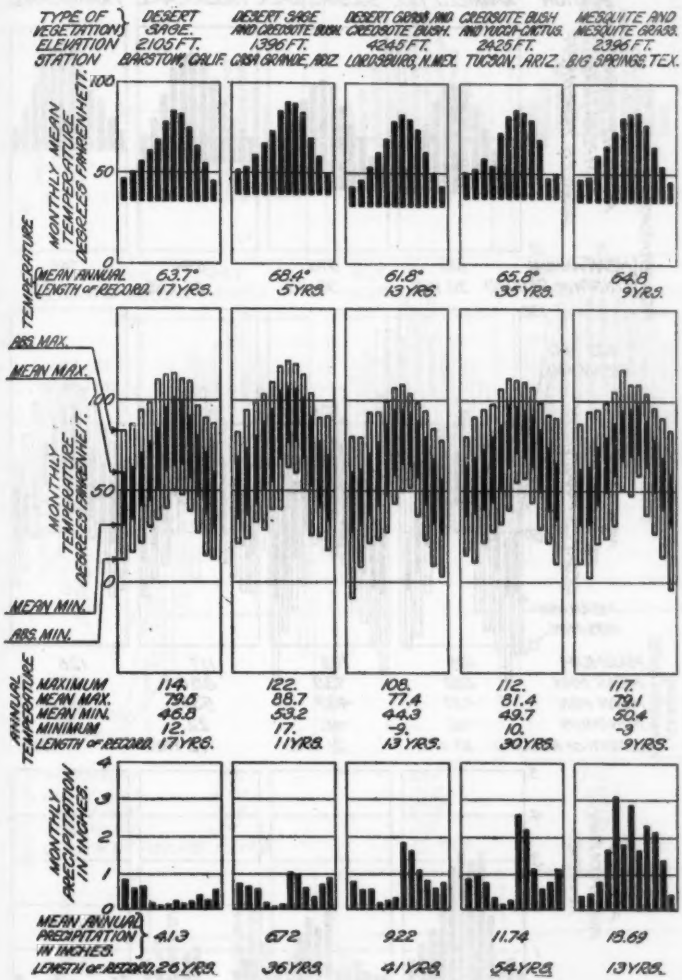

TYPE OF VEGETATION
ELEVATION
STATION
DESERT SAGE. 2105 FT. BARSTOW, CALIF.
DESERT SAGE AND CREOSOTE BUSH. 1396 FT. CASA GRANDE, ARIZ.
DESERT GRASS AND CREOSOTE BUSH. 4245 FT. LORDSBURG, N. MEX.
CREOSOTE BUSH AND YUCCA-CACTUS. 2425 FT. TUCSON, ARIZ.
MESQUITE AND MESQUITE GRASS. 2396 FT. BIG SPRINGS, TEX.
TEMPERATURE
MONTHLY MEAN TEMPERATURE DEGREES FAHRENHEIT.
100
50
0
MEAN ANNUAL
LENGTH OF RECORD
63.7° 17 YRS.
68.4° 5 YRS.
61.8° 13 YRS.
65.8° 35 YRS.
64.8 9 YRS.
ABS. MAX.
MEAN MAX.
MEAN MIN.
ABS. MIN.
MONTHLY TEMPERATURE DEGREES FAHRENHEIT.
ANNUAL TEMPERATURE
MAXIMUM 114. 122. 108. 112. 117.
MEAN MAX. 79.5 88.7 77.4 81.4 79.1
MEAN MIN. 46.8 53.2 44.3 49.7 50.4
MINIMUM 12. 17. -3. 10. -3
LENGTH OF RECORD 17 YRS. 11 YRS. 13 YRS. 30 YRS. 9 YRS.
MONTHLY PRECIPITATION IN INCHES.
4
3
2
1
0
MEAN ANNUAL PRECIPITATION IN INCHES.
4.13 6.72 9.22 11.74 18.69
LENGTH OF RECORD 26 YRS. 36 YRS. 41 YRS. 54 YRS. 13 YRS.

FIG. 17.—A comparison of vegetation with rainfall and temperature at Barstow, Calif.; Casa Grande and Tucson, Ariz.; Lordsburg, N. Mex.; and Big Springs, Tex. The graph shows monthly rainfall, monthly and annual mean, monthly absolute maximum and minimum, and monthly mean maximum and minimum temperatures for each station. In addition, the mean annual rainfall, the mean annual, the annual maximum, the mean maximum, the minimum, and the mean minimum temperatures, and the length of each record in years are given in figures below each graph. The type of vegetation and the name of the station with the elevation above sealevel are shown at the bottom of each column of graphs.

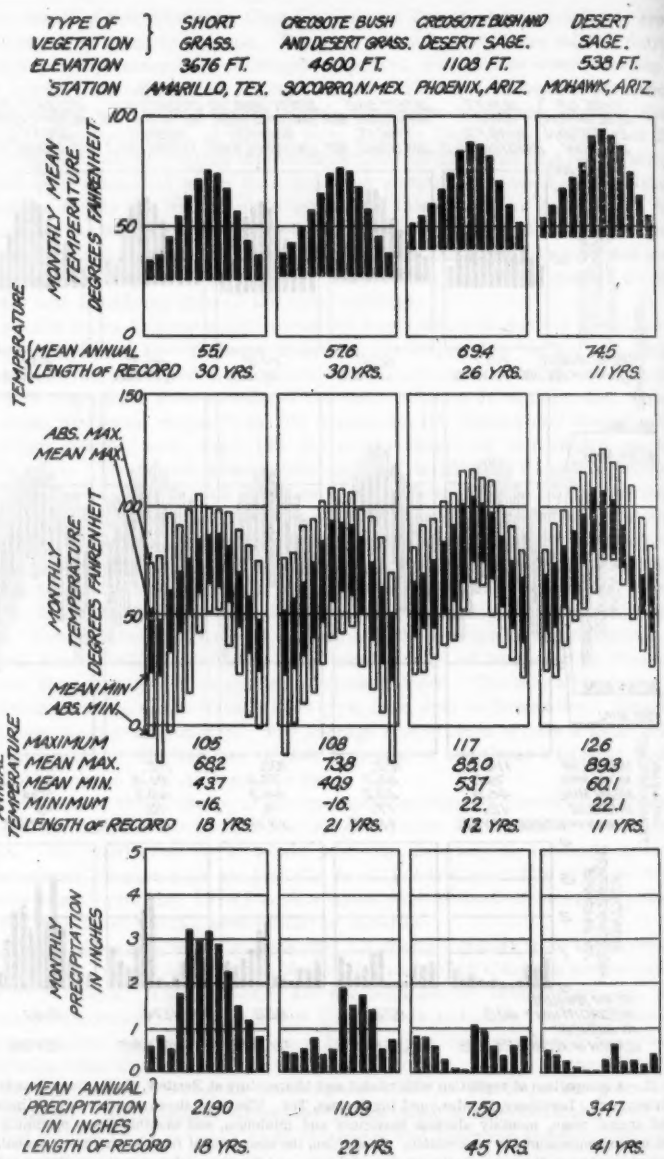


FIG. 18.—A comparison of the vegetation with rainfall and temperature at Mohawk and Phoenix, Ariz.; Socorro, N. Mex.; and Amarillo, Tex. The graph shows monthly rainfall, monthly and annual mean, monthly absolute maximum and minimum, and monthly mean maximum and minimum temperatures. In addition, the mean annual rainfall, the mean annual, the annual maximum, the mean maximum, the minimum and the mean minimum temperatures, and the length of each record in years are given in figures below each graph. The type of vegetation and the name of the station with the elevation above sealevel are shown at the bottom of each column of graphs.

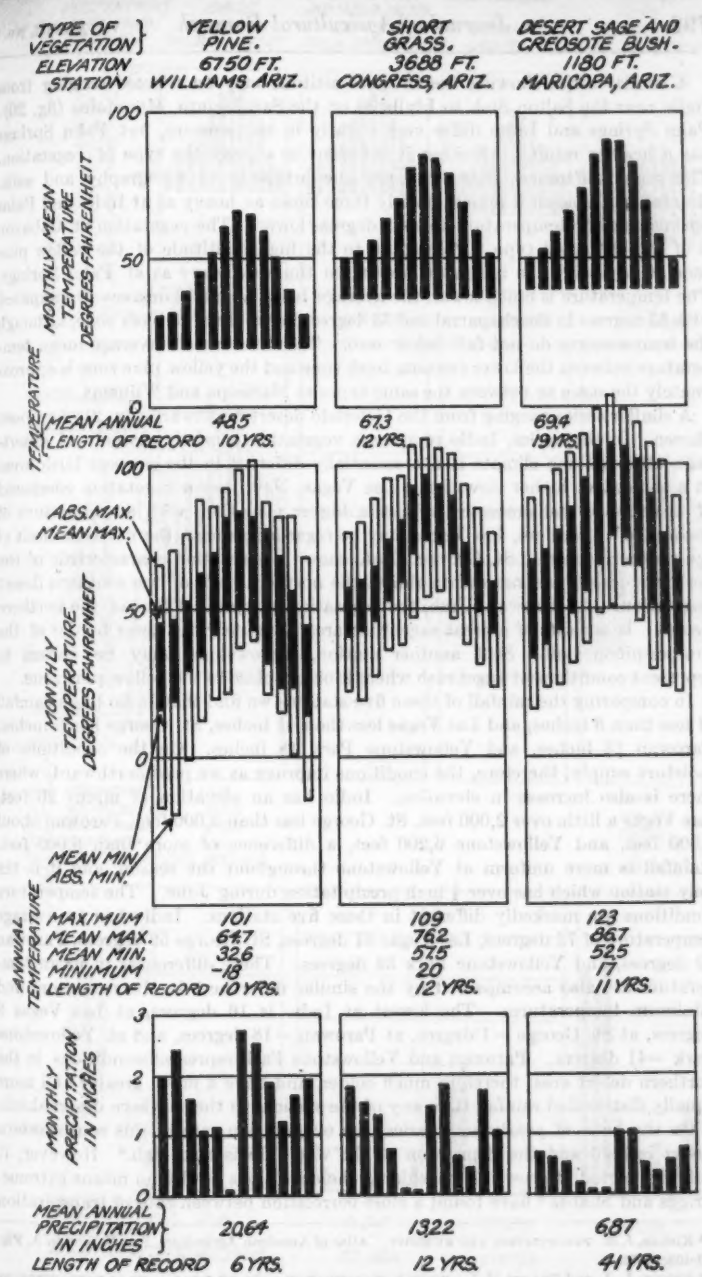


FIG. 19.—A comparison of the vegetation with rainfall and temperature at Maricopa, Congress, and Williams, Ariz. The graph shows monthly rainfall, monthly and annual mean, monthly absolute maximum and minimum, and monthly mean maximum and minimum temperatures. In addition, the mean annual rainfall, the mean annual, the annual maximum, the mean maximum, the minimum and the mean minimum temperatures, and the length of each record in years are given in figures below each graph. The type of vegetation and the name of the station with the elevation above sealevel are shown at the bottom of each column of graphs.

A similar series showing the effect of altitude may be selected ranging from Indio near the Salton Sink to Idyllwild on the San Jacinto Mountains (fig. 20). Palm Springs and Indio differ very slightly in temperature, but Palm Springs has a heavier rainfall. Neither is sufficient to change the type of vegetation. The slight differences that exist are due primarily to topography and soils. Rainfall at Cabazon is approximately three times as heavy as at Indio and Palm Springs and the temperature about 8 degrees lower. The vegetation at Cabazon is of the chaparral type. Proceeding to the higher altitude of the yellow pine zone at Idyllwild, the rainfall is about ten times as heavy as at Palm Springs. The temperature is much lower, the average being about 52 degrees as compared with 65 degrees in the chaparral and 73 degrees in the creosote bush zone, although the temperatures do not fall below zero. The difference in average mean temperature between the lower creosote bush zone and the yellow pine zone is approximately the same as between the same types at Maricopa and Williams.

A similar series ranging from the Colorado desert northward (fig. 21) has been chosen. In this series, Indio represents vegetation consisting largely of desert-sage, although the climate is not essentially different in the creosote bush areas at a somewhat higher elevation. Las Vegas, Nev., has a vegetation composed of desert-sage and creosote bush at a higher elevation, with an admixture of shadscale. Therefore, Las Vegas may be regarded as near the northern limit of the southern desert. St. George, Utah, shows a vegetation characteristic of the northern desert, and represents almost the northern limit of the southern desert vegetation. At Parowan, Utah, the vegetation is typical of that of the northern desert. It consists of a great sagebrush area lying near the lower border of the juniper-piñon belt. Still another station, Yellowstone, may be chosen to represent conditions of sagebrush where it occurs close to the yellow pine zone.

In comparing the rainfall of these five stations we find that Indio has a rainfall of less than 3 inches, and Las Vegas less than 4½ inches, St. George has 9 inches, Parowan 13 inches, and Yellowstone Park 18 inches. On the conditions of moisture supply, therefore, the conditions improve as we pass northward, where there is also increase in elevation. Indio has an elevation of minus 20 feet, Las Vegas a little over 2,000 feet, St. George less than 3,000 feet, Parowan about 6,000 feet, and Yellowstone 6,200 feet, a difference of more than 6,000 feet. Rainfall is more uniform at Yellowstone throughout the season, and it is the only station which has over ½ inch precipitation during June. The temperature conditions are markedly different in these five stations. Indio has an average temperature of 73 degrees, Las Vegas 61 degrees, St. George 59 degrees, Parowan 49 degrees, and Yellowstone Park 39 degrees. These differences in mean temperature are also accompanied by the similar differences in the maximum and minimum temperatures. The lowest at Indio is 16 degrees, at Las Vegas 8 degrees, at St. George −1 degree, at Parowan −18 degrees, and at Yellowstone Park −41 degrees. Parowan and Yellowstone Park represent conditions in the northern desert area, therefore much colder, and have a much greater and more equally distributed rainfall than any of the stations in the southern desert shrub.

On the basis of yearly summaries, the evaporation rate in this southwestern desert is high and the depression of the wet bulb is also high.[8] However, if only the period of growth is considered the conditions are by no means extreme. Briggs and Shantz [9] have found a close correlation between rate of transpiration

[8] KINCER, J. B. PRECIPITATION AND HUMIDITY. Atlas of American Agriculture, Part II, Section A, Fig. 103-105. 1922.

[9] BRIGGS, L. J., and SHANTZ, H. L. HOURLY TRANSPIRATION RATE ON CLEAR DAYS AS DETERMINED BY CYCLIC ENVIRONMENTAL FACTORS. Jour. Agr. Research 5:583-650, illus. 1916.

——— ———. DAILY TRANSPIRATION DURING THE NORMAL GROWTH PERIOD AND ITS CORRELATION WITH THE WEATHER. Jour. Agr. Research 7:155-212, illus. 1916.

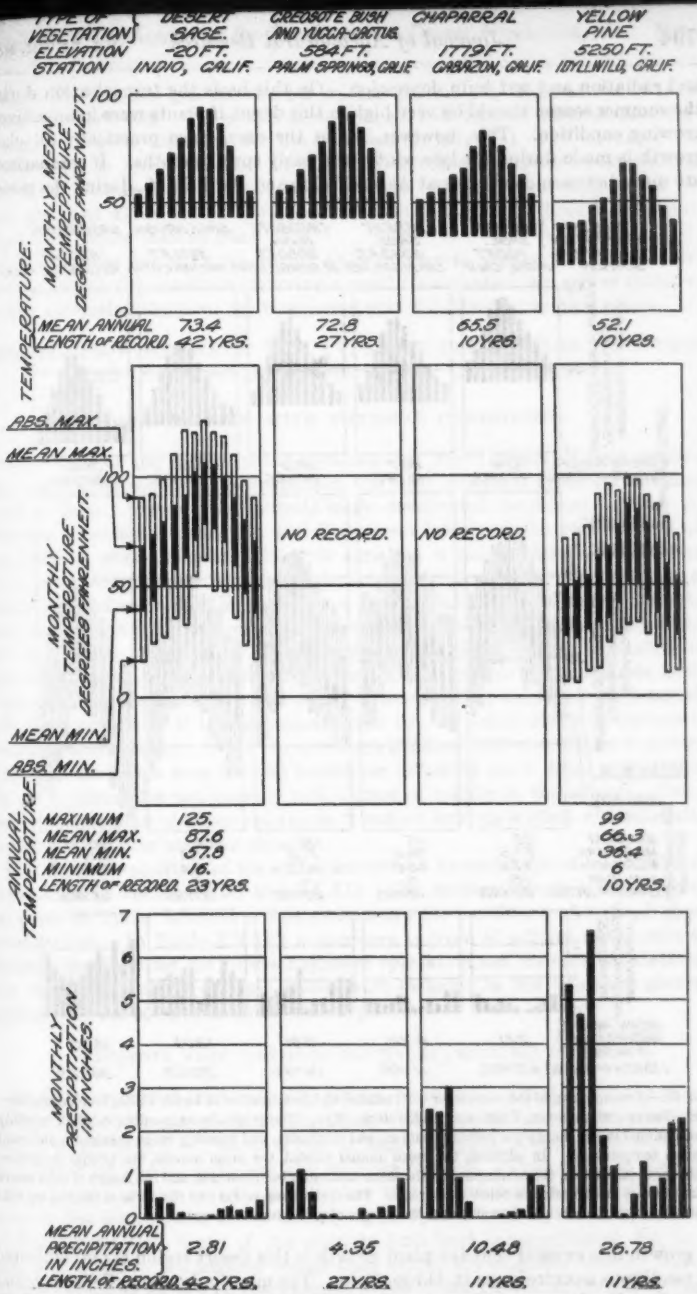


FIG. 20.—A comparison of the vegetation with rainfall and temperature at Indio, Palm Springs, Cabazon, and Idyllwild, Calif. The graph shows monthly rainfall, monthly and annual mean, monthly absolute maximum and minimum, and monthly mean maximum and minimum temperatures. In addition, the mean annual rainfall, the mean annual, the annual maximum, the mean maximum and minimum, and the mean minimum temperatures, and the length of each record in years are given in figures below each graph. The type of vegetation and the name of the station with the elevation above sealevel are shown at the bottom of each column of graphs.

and radiation and wet bulb depression. On this basis the transpiration during the summer season should be very high in this desert if plants were in an actively growing condition. This, however, is not the case, since practically all plant growth is made during the late winter and early spring months. If comparisons are made between conditions at Akron, Colo., and Bard, Calif., during the period

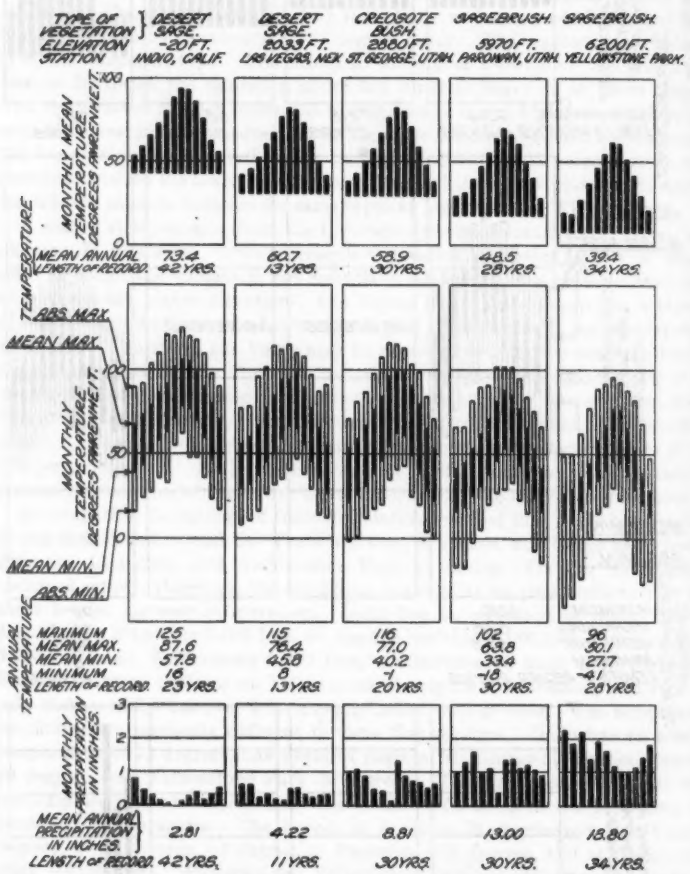


FIG. 21.—A comparison of the vegetation with rainfall and temperature at Indio, Calif., Las Vegas, Nev., St. George and Parowan, Utah, and Yellowstone, Wyo. The graph shows monthly rainfall, monthly and annual mean, monthly absolute maximum and minimum, and monthly mean maximum and minimum temperatures. In addition, the mean annual rainfall, the mean annual, the annual maximum, the mean maximum, the minimum and the mean minimum temperatures, and the length of each record in years are given in figures below each graph. The type of vegetation and the name of the station with the elevation above sealevel are shown at the bottom of each column of graphs.

of growth it is evident that the plant growth is this desert region is not subjected to conditions as extreme as at Akron, Colo. The months January, February, and March at Bard correspond as regards the time of active growth with May, June, and July at Akron, Colo. During these periods the light intensity [10] at Bard is

[10] KIMBALL, H. H. VARIATIONS IN THE TOTAL AND LUMINOUS SOLAR RADIATION WITH GEOGRAPHICAL POSITION IN THE UNITED STATES. Mo. Weather Rev. 47:769–793, illus. 1919.

between 300 and 500 gm. calories per sq. cm. per minute, while at Akron it is between 600 and 650. The evaporation from a 6-foot tank of water at Bard for January to March, inclusive, for the nine-year period, 1911–1919, averaged 12 inches, while at Akron for May to July, inclusive, for the thirteen-year period, 1908–1920, averaged 24 inches. A comparison of the water requirement of small grains at Akron and at Bard shows the requirements at Akron to be about 25 per cent higher than at Bard.

It is therefore evident that, in the Colorado desert, during the most active growing period, the conditions favoring a rapid transpiration are not so extreme as they are during the most active growing period in the central high plains.

CORRELATION BETWEEN THE TYPES OF VEGETATION AND THE CHARACTER AND PRODUCTIVITY OF THE LAND

CORRELATION WITH PHYSICAL CONDITIONS

While each of the valleys of the Southwestern desert region wherein studies were made differ somewhat in vegetation, the most important types are common to all of them. These types indicate fairly definite soil conditions. There is, however, considerable variation and the correct interpretation of the types of vegetation is often difficult. The wide variation in soil conditions where some of the types occur makes it necessary to know more than merely the fact that a certain type of vegetation is present on a piece of land. For instance, creosote bush throughout the southwestern desert region indicates well-drained, nonsaline land with a low water table. Whether the soil is of good depth or shallow is understood much better if it is known whether the growth of the creosote bush is tall and vigorous or scrubby and poor. Likewise, if the creosote bush is mixed with the bur-sage or if bur-sage occurs near by, the soil is likely to be looser, stonier and less fertile. If the creosote bush is mixed with desert-sage or occurs near the desert-sage area the soil conditions indicated are a finer, more fertile soil not so permeable and possibly with a trace of salinity in the subsoil. Creosote bush in regions of higher rainfall as in eastern Arizona is often characteristic of land with caliche near the surface.

The physical condition of the soil characterized by each type of vegetation is summarized in Tables XXXI and XXXII. The results of study of these tables are given in Table XXXIII which summarizes the conditions under each type of vegetation. In Table XXXIV a summary is given of salinity of the soils at different depths under the different types of vegetation and the different stations. The results of a study of these tables were included in the following general summary of the conditions under each type.

CREOSOTE BUSH (COVILLEA GLUTINOSA (ENGELM.) RYDB.)

While creosote bush land is usually porous, nonsaline and high above the water table, it is not always good farming land. That which is covered by a good growth of creosote bush, about 5 feet or higher, is good farming land having a good depth of porous nonsaline and well-drained soil. That which is covered with a poor, scrubby growth, usually less than 4 feet high, is land either too stony or else too shallow, due to underlying hardpan or rock layers, to be farmed. At the present time much of the creosote bush land is uncultivated, for, as a rule, it lies above the highest canals that supply the irrigation water. These lands, composing as they do the warmest slopes of the valleys, are probably best adapted to fruit culture.

TABLE XXXI.—*Comparison of the spring and fall soil conditions at the same stations in the principal plant communities at Indio, Calif., 1915* [a]

Item	Depth of soil	Plant community																					
		Creosote bush			Desert-sage			Mesquite and chamiso			Seepweed			Saltbush and arrowweed			Pickleweed			Saltgrass		
		Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average
Moisture equivalent	*Feet*																					
	1	3.3	3.7	3.5	24.0	24.2	24.1	2.3	2.6	2.5	23.5	27.1	25.3	28.3	27.8	28.1	23.1	20.6	21.9	27.1	29.7	28.4
	2	3.5	4.5	4.0	25.9	26.3	26.1	2.7	2.8	2.8	26.9	28.0	27.5	19.6	21.7	20.7	23.1	23.2	23.2	21.3	20.3	20.8
	3	2.8	3.9	3.4	23.0	23.9	23.5	2.6	2.8	2.7	20.7	19.8	20.3	16.0	19.8	17.9	18.2	18.1	18.2	35.5	30.1	32.8
	4	2.7	4.1	3.4	19.1	22.4	20.8	2.8	3.1	3.0	25.3	23.9	24.6	13.6	18.8	16.2	17.0	10.4	13.7	22.5	21.0	21.8
Wilting coefficient	1	1.8	2.0	1.9	13.1	13.2	13.2	1.3	1.4	1.4	12.7	14.7	13.7	15.3	15.1	15.2	12.6	11.2	11.9	14.7	16.2	15.4
	2	1.9	2.5	2.2	14.1	14.3	14.2	1.5	1.6	1.6	14.6	15.2	14.9	10.7	11.9	11.2	12.5	12.7	12.6	11.6	11.0	11.3
	3	1.5	2.1	1.8	12.6	13.0	12.8	1.4	1.5	1.5	11.3	10.7	11.0	8.7	10.8	9.8	9.9	9.8	9.9	19.3	16.4	17.9
	4	1.5	2.2	1.9	10.4	12.2	11.3	1.5	1.7	1.6	13.8	13.0	13.4	7.4	10.2	8.8	9.2	5.6	7.4	12.3	11.4	11.9
Moisture content above or below wilting coefficient.	1	+3.0	−1.2	.....	+3.3	−10.2	.....	+2.4	−1.3	.....	+5.7	−10.8	.....	+14.1	0.0	.....	+17.5	+5.8	.....	+16.3	+5.4	.....
	2	+4.4	−1.6	.....	−2.9	−8.5	.....	+3.8	−1.0	.....	+8.2	−5.7	.....	+12.5	+4.1	.....	+16.1	+9.0	.....	+17.4	+9.8	.....
	3	+4.4	−1.4	.....	−4.2	−6.6	.....	+4.1	−0.3	.....	+4.2	+0.1	.....	+12.0	+4.1	.....	+18.4	+13.2	.....	+17.1	+14.3	.....
	4	+2.3	−1.3	.....	−5.1	−6.6	.....	+0.4	−0.1	.....	+2.3	+0.6	.....	+16.4	+8.3	.....	+20.8	+12.0	.....	+19.4	+17.7	.....
	Average	+3.5	−1.4	.....	−2.2	−8.0	.....	+2.7	−0.7	.....	+5.1	−3.9	.....	+13.8	+4.1	.....	+19.1	+10.0	.....	+17.6	+11.8	.....
Salt content	1	.01	.01	.01	.26	.25	.26	.01	.01	.01	.99	1.09	1.04	>2.50	2.13	2.32	>2.50	>2.50	>2.50	2.45	2.08	2.27
	2	.01	.01	.01	.70	.40	.55	.01	.01	.01	.69	1.05	.87	.63	1.35	.99	1.86	1.38	1.62	1.27	1.32	1.30
	3	.01	.01	.01	.32	.22	.27	.02	.01	.02	.50	.95	.73	.28	.50	.39	1.17	.92	1.05	.36	1.03	.70
	4	.01	.01	.01	.27	.21	.24	.02	.04	.03	.78	.75	.77	.20	.49	.35	.48	.44	.46	.20	.53	.37
	Average	.01	.01	.01	.39	.27	.33	.02	.02	.02	.77	.96	.87	.90	1.12	1.01	1.50	1.31	1.41	1.07	1.24	1.16

[a] All data in this table are stated in percentages of the dry weight of the soil.

TABLE XXXII.—*Comparison of the spring and fall soil conditions at the same stations in the principal plant communities at Chandler, Ariz., 1915* [a]

TABLE XXXII.—*Comparison of the spring and fall soil conditions at the same stations in the principal plant communities at Chandler, Ariz., 1915* [a]

Item	Depth of soil	Plant communities														
		Creosote bush			Desert-sage			Chamiso "sand bars"			Saltbush			Giant cactus and paloverde		
		Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average	Spring	Fall	Average
	Feet															
Moisture equivalent	1	9.8	11.3	10.6	12.6	11.7	12.2	6.2	7.2	6.7	20.3	21.0	20.7	13.4	17.6	15.5
	2	12.0	13.6	12.8	14.7	14.5	14.6	7.4	8.1	7.8	19.9	20.4	20.2	15.3	21.5	18.4
	3	14.8	15.5	15.2	15.5	15.7	15.6	9.8	10.6	10.2	20.4	20.4	20.4	15.4	26.5	21.0
	4	15.3	15.9	15.6	14.5	16.3	15.4	10.3	12.4	11.4	23.1	22.9	23.0	13.2	19.1	16.2
Wilting coefficient	1	5.3	6.1	5.7	6.8	6.4	6.6	3.4	3.9	3.7	11.1	11.4	11.3	7.3	9.6	8.5
	2	6.5	7.4	7.0	8.0	7.9	8.0	4.0	4.4	4.2	10.9	11.1	11.0	8.3	11.7	10.0
	3	8.0	8.4	8.2	8.4	8.5	8.5	5.3	5.8	5.6	11.1	11.1	11.1	8.4	14.4	11.4
	4	8.3	8.6	8.6	7.9	8.9	8.4	5.6	6.7	6.2	12.6	12.5	12.6	7.2	10.4	8.8
Moisture content above and below wilting coefficient.	1	+0.1	−4.2	.....	+1.0	−4.4	.....	+1.2	−3.1	.....	+12.4	+6.7	.....	−0.9	−3.0	.....
	2	+1.6	−3.1	.....	+3.5	−2.0	.....	+3.2	−1.3	.....	+18.5	+9.9	.....	+2.5	−3.7	.....
	3	+2.3	−4.2	.....	+2.7	+0.1	.....	+4.0	−0.3	.....	+20.9	+11.2	.....	+2.7	−6.6	.....
	4	+1.8	−3.7	.....	+3.0	+0.4	.....	+4.4	+0.1	.....	+19.7	+11.2	.....	+3.3	+0.5	.....
	Average	+1.5	−3.8	.....	+2.6	−1.5	.....	+3.2	−1.2	.....	+17.9	+9.8	.....	+2.4	+3.2	.....
Salt content	1	.02	.07	.05	.04	.08	.06	.02	.02	.02	.61	.90	.76	.07	.11	.09
	2	.03	.04	.04	.21	.25	.23	.01	.11	.06	.40	.84	.62	.10	.09	.10
	3	.04	.06	.05	.35	.34	.35	.04	.11	.08	.38	.56	.47	.17	.14	.16
	4	.08	.08	.08	.49	.35	.42	.16	.15	.16	.35	.87	.61	.34	.26	.30
	Average	.04	.06	.06	.27	.26	.27	.06	.10	.08	.44	.79	.62	.17	.15	.16

[a] All data in this table are stated in percentages of the dry weight of the soil.

TABLE XXXIII.—*A summary of the soil conditions as indicated by the principal plant communities of the Southwestern Desert*

Types of vegetation	Condition of vegetation	Kind of soil		Moisture		Salinity	
		Surface foot	Subsoil	Surface foot	Subsoil	Surface foot	Subsoil
Creosote bush	Good growth	Sandy loam	Sandy loam	Moist after rains only	Moist after rains only	Nonsaline	Nonsaline.
	Poor growth	Often stony or if as above (see under subsoil).	Hardpan or rock layer more rarely alkali.	do	Apt to be dry due to lack of penetration.	do	Rarely slightly saline.
Desert-sage	Good growth	Fine sandy loam	Fine sandy loam	do	Moist after rains only	do	Nonsaline.
	Poor growth	do	Hardpan or alkali	do	Apt to be dry due to lack of penetration.	do	Saline.
Mesquite and chamiso.		Sand	Sand	do	Moist after rains only	do	Nonsaline.
Chamiso		Sandy	Sandy	do	do	do	Do.
Seepweed	Rank growth	Fine sandy loam	Fine sandy loam	Moist* in spring. Rains and high water table.	Moist* most of year. High water table.	Saline*	Saline.*
	Poor growth	do	do	Moist only after rains.	Moist part of year. Rains and high water table.	do	Do.
Saltbush and arrowweed.		Loam	Fine sandy loam with sand layers.	Moist most of year. High water table.	Moist all the year. High water table.	Strongly saline	Moderately saline.
Pickleweed		Fine sandy loam to loam.	do	Moist all the year. High water table.	Wet all the year. High water table.	do	Strongly saline.
Saltgrass		Clay loam, fine sandy loam. Sand and gravel, etc.	Clay loam, fine sandy loam. Sand and gravel, etc.	do	do	do	Do.
Mesquite thicket		Clay loam	Clay loam	Moist after rains only	Moist all the year. High water table.	Slightly saline	Do.
Saltbush		Heavy clay loam	Heavy clay loam	Wet most of the year. High water table.	Wet all the year. High water table.	Saline	Saline.

* Except where it is a weed, as on an abandoned field; then a rank growth may indicate nonsaline soil and temporary moisture.

TABLE XXXIV.—*Salt content of the soils occupied by the principal plant communities of the Southwestern Desert* [a]

Depth of soil	Creosote bush (*Covillea glutinosa*)				Desert-sage (*Atriplex polycarpa*)					Seepweed (*Dondia torreyana* and *D. intermedia*)				Mesquite and chamiso (*Prosopis glandulosa-Atriplex canescens*)			
	Indio, 1915, 10 samples	Chandler, 11 samples	Casa Grande, 4 samples	Average	Indio, 1914, 26 samples	Indio, 1915, 10 samples	Chandler, 16 samples	Casa Grande, 3 samples	Average	Indio, 1914, 9 samples	Indio, 1915, 6 samples	Casa Grande, 1 sample	Average	Indio, 1915, 10 samples	Chandler, 8 samples	St. George, 1 sample	Average
Feet																	
1	0.01	0.05	0.02	0.03	0.30	0.26	0.06	0.04	0.17	1.55	1.04	0.25	0.95	0.01	0.02	0.12	0.05
2	.01	.04	.02	.02	.45	.55	.23	.07	.33	1.25	.87	.50	.87	.01	.06	.12	.06
3	.01	.05	.03	.03	.33	.27	.35	.08	.26	.89	.73	1.04	.89	.02	.08	.14	.08
4	.01	.08	.05	.05	.31	.24	.42	.14	.28	.77	.77	.70	.75	.03	.16	.19	.13
Average	.01	.06	.03	.03	.35	.33	.27	.08	.26	1.12	.87	.62	.90	.02	.08	.14	.08

Depth of soil	Saltbush and arrow-weed (*Atriplex lentiformis-Pluchea sericea*)			Saltbush (*Atriplex lentiformis*)			Pickleweed (*Allenrolfea occidentalis*)			Saltgrass (*Distichlis spicata*)		
	Indio, 1914, 2 samples	Indio, 1915, 6 samples	Average	Indio, 1914, 2 samples	Chandler, 6 samples	Average	Indio, 1914, 7 samples	Indio, 1915, 6 samples	Average	Indio, 1914, 3 samples	Indio, 1915, 4 samples	Average
Feet												
1	1.19	2.32	1.76	>2.50	0.76	1.63	1.78	2.50	2.14	1.80	2.27	2.04
2	.66	.99	.83	.44	.62	.53	1.46	1.64	1.55	1.23	1.30	1.27
2	.66	.39	.53	.22	.47	.35	1.21	1.05	1.13	.94	.70	.82
4	.70	.35	.53	.12	.61	.37	.78	.46	.62	.69	.37	.53
Average	.80	1.01	.91	.82	.62	.72	1.31	1.41	1.38	1.17	1.16	1.17

[a] All data in this table are stated in percentages of the dry weight of the soil.

DESERT-SAGE (ATRIPLEX POLYCARPA (TORR.) S. WATS.)

Probably the largest part of the land now under irrigation in the Coachella and Gila Valleys is desert-sage land. While this land is usually slightly saline, with irrigation the amount of salt is not prohibitive. Here, as in the case of creosote bush land, the condition of the desert-sage means much. Where there is a pure good growth of desert-sage the soil is a nonsaline sandy loam, considerably above the water table. Where the growth is poor, however, the salinity increases considerably and, in some cases, there is a hardpan. Though the saline content is rarely high enough to be serious, yet the silty layers of soil, or sometimes the hardpan, may make it difficult to remove the salts by leaching. Both fruits and alfalfa are grown on this type of land to a large extent.

SEEPWEED (DONDIA TORREYANA (S. WATS.) STANDL.) AND DONDIA INTERMEDIA (S. WATS.) HELLER

Seepweed is an almost infallible indicator of alkali. Occasionally land is found that is covered with it but is not saline, in which case the growth is weedy, coming in on abandoned land where the original vegetation had been destroyed. Land covered with a pure growth of it is strongly saline. Even where there are other plants and only scattered plants of the seepweed, the soil is usually quite strongly saline. If covered with a rank growth of the seepweed the water table is sure to be high. Seepweed land requires considerable leaching and often draining before it can be used profitably for farming.

MESQUITE AND CHAMISO (PROSOPIS GLANDULOSA TORR. AND ATRIPLEX CANESCENS (PURSH) NUTT.)

This land consists of sand dunes, in the Coachella Valley, and low sandy ridges, in the Gila Valley. In the former valley the total acreage of the sand dune area is large, but in the latter, where mesquite and chamiso are supplanted by chamiso the areas are small and scattered. In either case the land is very sandy and nonsaline. In the Coachella Valley the more level tracts of this land are being used for date and vegetable growing. These are relatively small areas, for the greater part of this type of land, the high sand dunes, can not be farmed. In the Gila Valley vegetables and grain are grown on this land.

SALTBUSH AND ARROWWEED (ATRIPLEX LENTIFORMIS (TORR.) S. WATS. AND PLUCHEA SERICEA NUTT.) COVILLE

Because of the high salt content and the high water table it is necessary to drain this type of land before it can be farmed permanently. In the Coachella Valley this type of land ought to drain readily because of the sandy layers in the subsoil while in the Gila Valley drainage may be more difficult since the subsoil is very heavy. Most of the land once farmed and later abandoned because of the high water table becomes overgrown with saltbush or saltbush and arrowweed. With proper drainage, however, good crops of alfalfa ought to grow again on this land.

PICKLEWEED (ALLENROLFEA OCCIDENTALIS (S. WATS.) KUNTZE)

This is the most saline of any of the types of land considered. Moreover the water table is high, so high that in spring the land is boggy and therefore drainage is essential if crops are to be grown.

SALTGRASS (DISTICHLIS SPICATA (L.) GREENE)

Meadows of saltgrass furnish a natural pasturage but the water table is so high and the salt content so great that drainage is necessary before crops can be grown on this type of land.

AGRICULTURAL POTENTIALITY OF THE LAND CHARACTERIZED BY EACH PLANT COMMUNITY

Probably the best type of land for irrigation agriculture is that characterized by a good stand of desert-sage. A good stand of creosote bush indicates land which has good drainage and which is free from alkali, but the soil is usually more sandy and not as productive as that occupied by the desert-sage. Mesquite and chamiso, and chamiso alone, indicate a very sandy soil free from alkali. Yucca and cactus lands, and giant cactus and paloverde lands, are too stony or the slope is too steep. Seepweed, saltbush, saltbush and arrowweed, pickleweed, and saltgrass lands must be leached and usually drained before they will be productive under irrigation. The adaptability of lands, characterized by different types of vegetation, for crop production under irrigation is shown in Table XXXV.

TABLE XXXV.—*The capability of lands for crop production as indicated by the principal plant communities of the Southwestern Desert*

Type of vegetation	Condition of vegetation	Is land capable of crop production under irrigation?
Creosote bush	Good growth	Yes.
	Poor growth	Doubtful because of stony soil or layer of rock or hardpan.
Desert-sage	Good growth	Yes.
	Poor growth	Doubtful because of presence of hardpan or alkali or both.
Mesquite and chamiso		Not the greater part, small more level tracts for special crops.
Chamiso		Yes.
Mesquite thicket		Yes; if handled so that salts are leached out.
Seepweed	Rank growth	Probably if secondary growth on abandoned land. If virgin growth, salt must be leached out and land drained.
	Poor growth	Salts must be leached out. Drainage may be necessary.
Saltbush and arrowweed		Yes; if it is drained.
Saltbush		Do.
Pickleweed		Only if it is drained and salts are leached out.
Saltgrass		Do.
Yucca—cactus and giant cactus—paloverde		Usually too stony or slope too steep.

PLATE 1

A.—General view of the bad lands northwest of Indio, Calif. The vegetation, largely annuals, is very sparse. Indio, Calif., Apr. 20, 1913.

B.—Yucca and cactus association. Detail showing the rough and stony character of the land usually occupied by this association, and also the variety of plant forms including *Ferocactus acanthodes* (Lemaire.) Britton & Rose, *Opuntia bigelovii* Engelm., and *Encelia farinosa* A. Gray. Near Palm Canyon, Calif., March 8, 1915.

A

B

A

B

PLATE 2

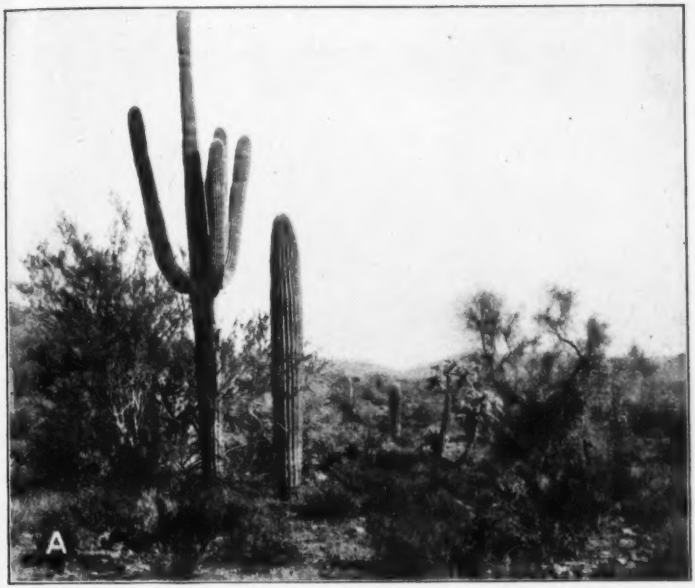
A.—*Parosela arborescens* (Torr.) Heller characteristic of washes in this portion of the desert. Many other plants are usually associated with it. West of Imperial, Calif., April 21, 1918.

B.—Giant cactus and paloverde association. Illustrates the rough and stony character of the soil and the variety of plant forms. Prominent in the picture are *Covillea glutinosa* (Engelm.) Rybd., *Franseria dumosa* A. Gray, *F. deltoides* Torr., *Carnegiea gigantea* (Engelm.) Britton & Rose, *Ferocactus wislizeni* (Engelm.) Britton & Rose, *Opuntia bigelovii* Engelm., *Fouquieria splendens* Engelm., *Cercidium torreyanum* (S. Wats.) Sarg., *Encelia farinosa* A. Gray, etc. North of Sacaton, Ariz., March 13, 1915.

PLATE 3

A.—Giant cactus and paloverde association. A more level area showing *Carnegiea gigantea* (Engelm.) Britton & Rose, *Cercidium torreyanum* (S. Wats.) Sarg., *Olneya tesota* A. Gray, *Opuntia bigelovii* Engelm., *Covillea glutinosa* (Engelm.) Rydb., *Franseria dumosa* A. Gray, etc. Near Sacaton, Ariz., March 13, 1915.

B.—Creosote bush association. A pure stand of *Covillea glutinosa* (Engelm.) Rydb., with wide spaces of bare soil between the plants and, in the background, a very few associated shrubs. Nipton, Calif., September 14, 1915.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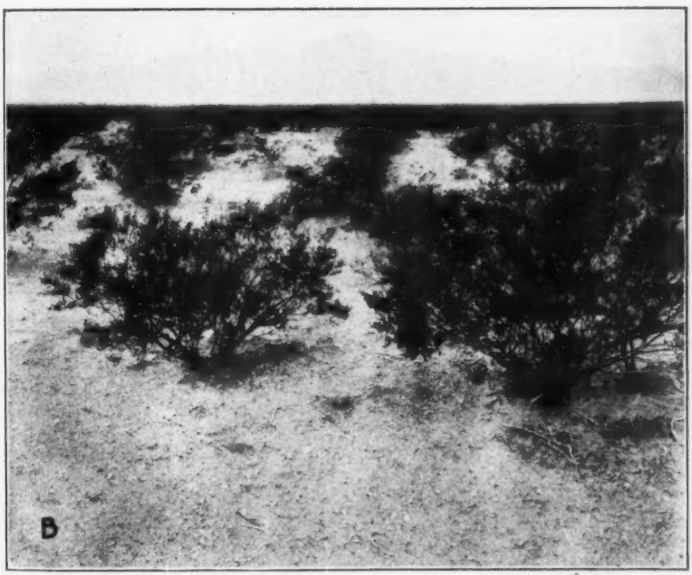
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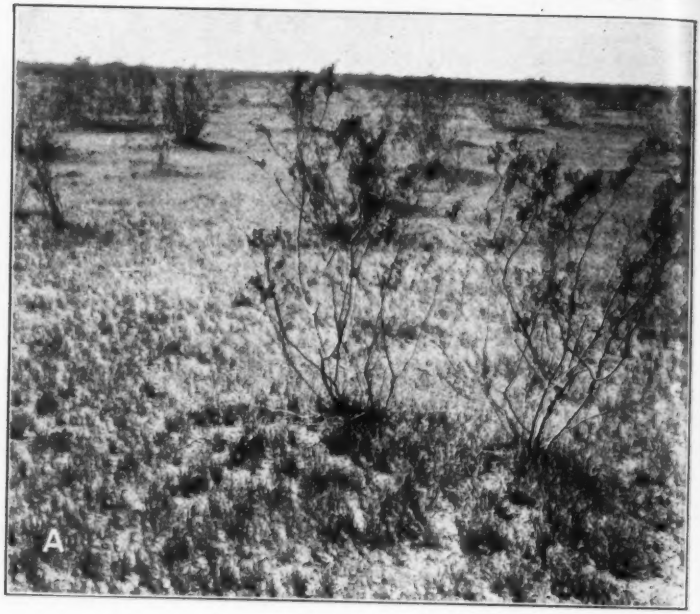

A

B

PLATE 4

A.—Creosote bush association. A pure stand of *Covillea glutinosa* (Engelm.) Rydb. The wide spaces between the plants are well covered with an ephemeral growth of *Plantago erecta* Morris. This condition is found only following a period of rainy weather, and the annual vegetation entirely disappears during the long drought periods. (See Pl. 3, B.) Chandler, Ariz., March 15, 1915.

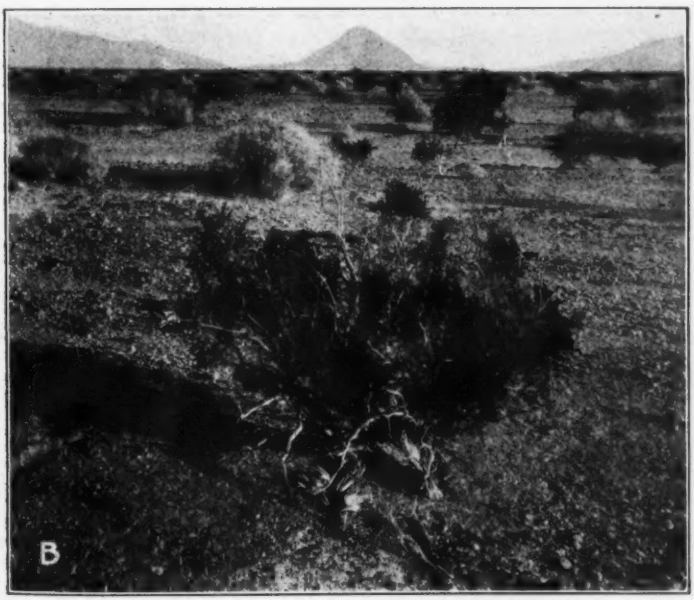
B.—A plant of *Covillea glutinosa* (Engelm.) Rydb. showing the loose open branching of the top and the spreading habit of the root system which is well adapted to utilize the soil moisture of the wide spaces between the plants. Indio, Calif., March 7, 1915.

PLATE 5

A.—Creosote bush and bur-sage. An open stand of good *Covillea glutinosa* (Engelm.) Rydb. with many plants of *Franseria dumosa* A. Gray occurring in the interspaces. The Covillea with its dark green lacquered leaves appears almost black, and contrasts sharply with Franseria which is silvery in color and, at a distance, appears almost pure white. Palm Springs, Calif., March 7, 1915.

B.—An open stand of creosote bush with desert-sage. The contrast in color of the two plants is very sharp. *Covillea glutinosa* (Engelm.) Rydb. is very dark green and *Atriplex polycarpa* (Torr.) S. Wats. an ashy gray. Death Valley Junction, Calif., September 15, 1915.

A


B

A

B

PLATE 6

A.—In the foreground Isocoma has come in to occupy the land previously covered with desert-sage. The original growth of desert-sage is shown in the middle of the photograph with thickets of mesquite in the background. The mesquite is here parasitized by *Phoradendron californicum* Nutt. Indio, Calif., March 21, 1913.

B.—Desert-sage association. A pure stand of *Atriplex polycarpa* (Torr.) S. Wats. presenting a uniform, ash-colored, shrubby growth about 3 feet in height. Such vegetation characterizes the best agricultural land of the desert valleys. South of Indio, Calif., March 6, 1915.

PLATE 7

A.—A single plant of seepweed showing the nature of the top and the root system to a depth of 2 feet. A salt crust which covers much of the seepweed land is here clearly shown. Thermal, Calif., March 5, 1915.

B.—A plant of *Atriplex polycarpa* (Torr.) S. Wats. showing the character of the root system with a tap root of over 5 feet. At a depth of 1 foot many laterals are developed, indicating that the plant receives most of its growth water from about this depth of soil. Near Indio, Calif., March 7, 1915.

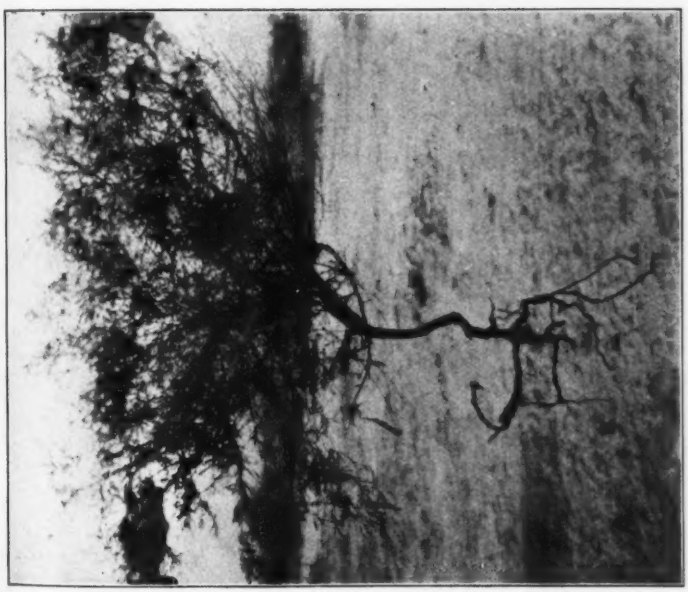


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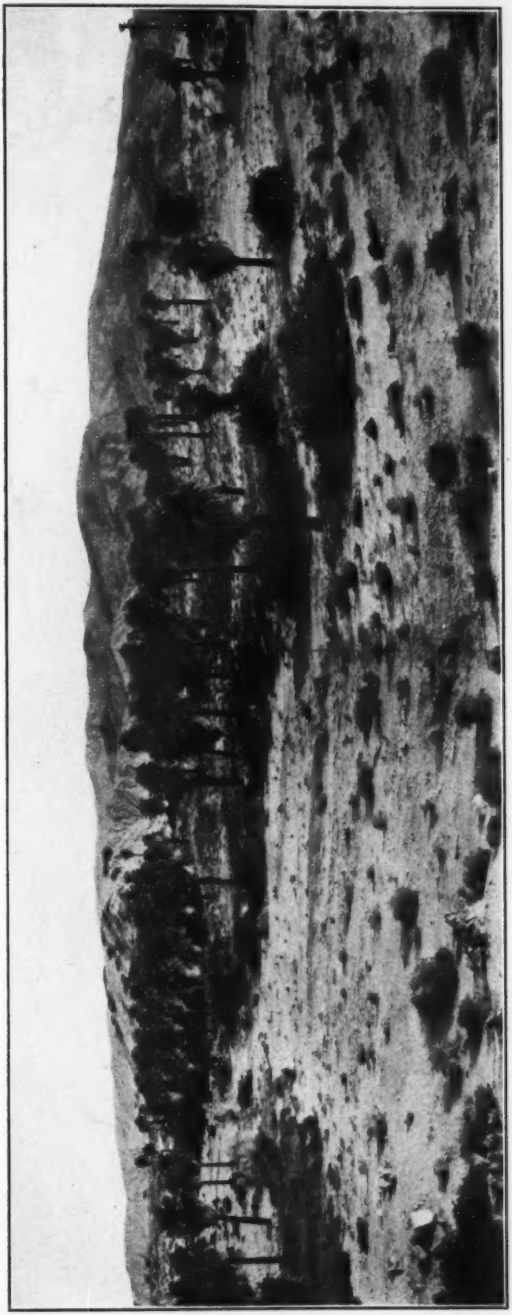
PLATE 8

A.—Saltgrass association. An even stand of *Distichlis spicata* (L.) Greene with Allenrolfea in the background. This photograph shows boring No. 12, Table XVII. Thermal, Calif., September 14, 1914.

B.—Pickleweed association. Practically pure Allenrolfea with bare salt incrusted areas between the plants. The plants are dark brownish green during much of the season. Sample 9, Table XX, was taken at this place. Thermal, Calif., September 14, 1914.

PLATE 9

Washington palms. A scattered growth of *Washingtonia filifera* Wendl. at the upper edge of the valley just below the clay hills showing the associated *Juncus robustus* S. Wats., *Imperata hookerii* Rupr., *Distichlis spicata* (L.) Greene, etc. North of Indio, Calif., April 20, 1913.



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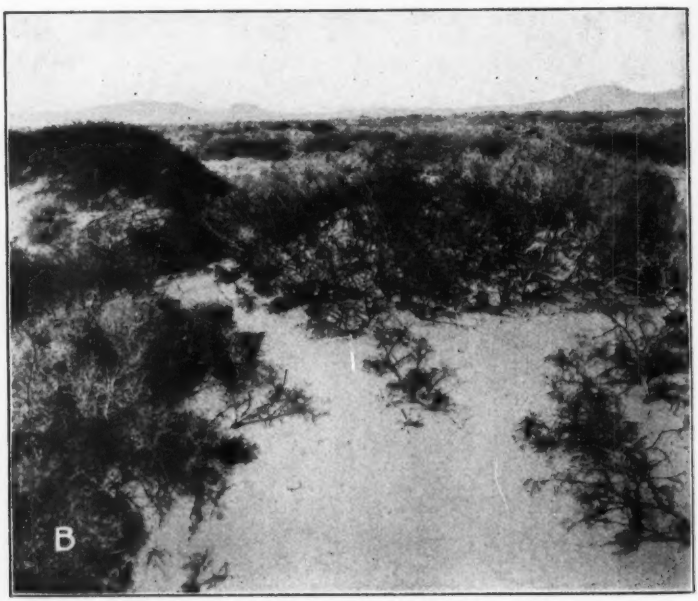
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PLATE 10

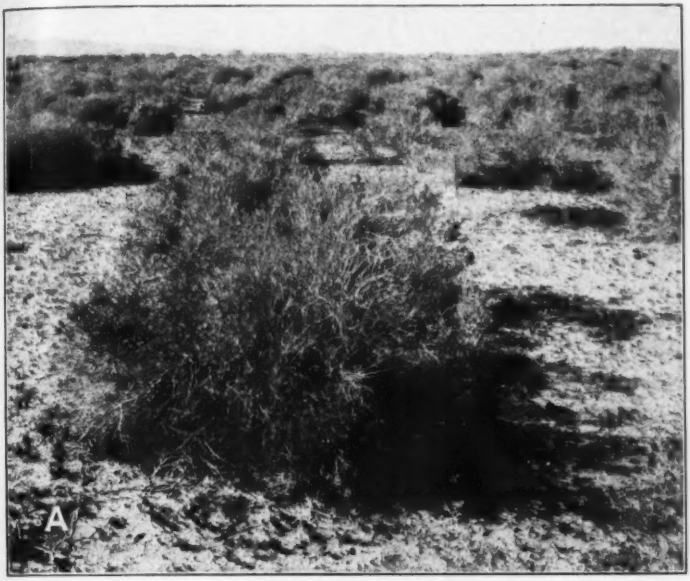
A.—A single plant of Allenrolfea inverted on the salt crust to show the character of the root system. The root extended to a depth of 2 feet. Thermal, Calif., March 6, 1915.

B.—Mesquite and chamiso community. Only the upper branches of the mesquite stand above the sand. The lighter-colored plants contrasting with the darker foliage of the mesquite are chamiso bushes. Las Vegas, Nev., September 11, 1914.

PLATE 11

A.—A pure stand of chamiso with many annuals occupying the interspaces as it appears on the "sand bars" in the Gila Valley. This photograph was taken at boring No. 2. (See Table XXII.) Chandler, Ariz., March 16, 1915.

B.—An old plant of *Atriplex canescens* (Pursh) Nutt. (chamiso) illustrating the habit of its roots on a sandy soil. The lateral root measured more than 9 feet. The top, with very few leaves, is characteristic of the plants at this time of the year. Indio, Calif., September 15, 1914.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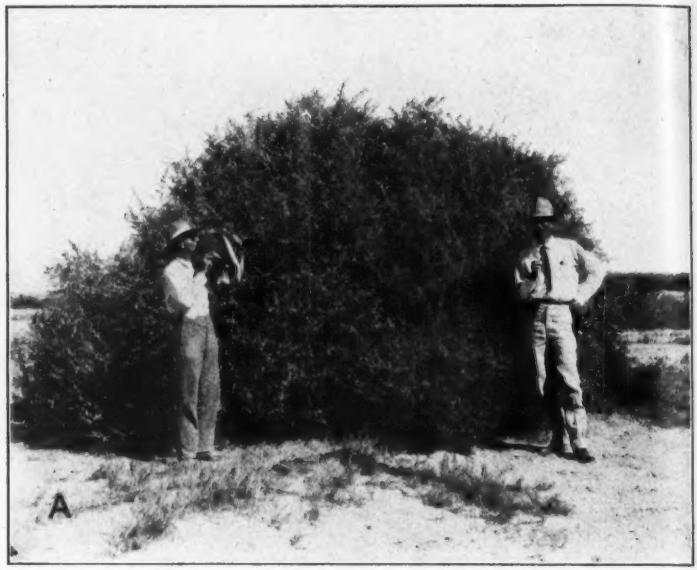
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PLATE 12

A.—A saltbush, showing the large size which it attains under favorable conditions. Mecca, Calif., September 16, 1914.

B.—A rank dense growth of arrowweed in Coachella Valley. Photographed near sample 15. (See Table I.) Indio, Calif., September 15, 1914.

PLATE 13

A.—Seepweed land illustrating an area where "seep" or water heavily charged with salt has come to the surface and incrusted an old plant of seepweed. Thermal, Calif., March 5, 1915.

B.—Revegetation on seepweed land, a dense growth of young seepweed plants following breaking, and, in the background, sand dunes covered with mesquite. Indio, Calif., March 7, 1915.

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B

A

B

PLATE 14

A.—Seepweed association. A dense stand of seepweed with the soil area between covered with salt incrustations. This photograph was taken near sample No. 13. (See Table XXVI.) Thermal, Calif., September 14, 1914.

B.—A bare flat, slick during wet weather, but hard as cement during the dry season. No plants occur on such areas. Mina, Nev., September 29, 1916.

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ACROMANIA, OR "CRAZY-TOP," A GROWTH DISORDER OF COTTON[1]

By O. F. Cook

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THE NATURE OF GROWTH DISORDERS

Some of the diseases of cotton are manifested by abnormal growth of the plants, without localized injuries like those associated with parasitic fungi or bacteria. A remarkable feature of growth disorders is that the plant characters and habits of growth may be changed suddenly, the normal characters being replaced by abnormalities of many kinds and degrees. The changes of characters often are so complete that the abnormal growth would not be recognized as belonging to the same variety as the early growth of the same plant, or even to the same species, if the connection were not known. To appreciate the extent of the abnormalities, it is necessary to be familiar with the normal characters and development of the plants, as in the study of breeding and adaptation of varieties.

Similar disorders affect other plants, and some of them are known as mosaic diseases, because the leaves are discolored in irregular patchwork areas of light and dark green. But in crazy-top the growth is abnormal in other ways, without discoloration of the leaves. Some of the disorders are temporary, with a later return to normal growth, while other disorders are permanent so that the abnormalities continue to appear in all of the new growth that takes place. When the changes of characters are permanent the growth disorders appear somewhat analogous to "bud mutations."

Since the symptoms of crazy-top are aggravated by stress conditions, it might be expected that the cause would be found in some peculiarity of the environment. The presence of harmful substances in the soil is easy to assume and difficult to disprove, but with crazy-top there is no indication that any particular type or condition of soil is associated. The disease occurs under a wide range of cultural conditions, and appears sporadically in scattered individuals, as well as in more compact groups of plants, or in large areas. The mode of occurrence of crazy-top is consistent with the possibility of an infection distributed by insects. It is known that several of the mosaic diseases of other plants are carried by insects, and that some of the diseases are very infectious, so that only slight surface contacts are necessary to spread the "virus."

The underlying cause of mosaic diseases is still obscure, even with those that have been studied most carefully, as in sugar-cane, sugar-beets, tobacco, and potatoes. Some pathologists credit the idea of very minute Protozoa, smaller than bacteria, beyond the limit of microscopic vision, as indicated by the passage of contagious "virus" of mosaic disorders through filters that are impermeable to bacteria. Other investigators have sought for causes of such diseases in organic poisons, or in the reactions of organic ferments or "enzymes." The causes, no doubt, are different for the disorders that are not permanent nor infectious, though one of the temporary disorders of cotton is due to plant lice. Another may be a physical injury or traumatism, primarily affecting the oil-

[1] Received for publication May 1, 1924.

glands. Still another class of disorders might be described as genetic, since they either are inherited or are closely connected with genetic factors.

If organisms are involved in crazy-top, they doubtless are able to live continuously in the cells without destroying the protoplasm, like the bacteria that produce crown-galls. Organisms that cause permanent disorders must be adapted or adjusted in some manner against increasing to large numbers that would destroy the host-plant. Since it would be to the advantage of such parasites to injure their host-plants as little as possible, the tendencies of natural selection with parasites as well as with the plants themselves would be in the direction of less serious injuries. Thus a condition of immunity might be reached in which little or no injury would be apparent. An immunity of tolerance might exist in some species of plants and an immunity of resistance in others.

The different degrees to which the adjoining areas of leaf tissue are affected, as shown in the mottled discolorations of the leaves in the mosaic diseases, would indicate delicately balanced conditions of the tissues in relation to the disease. It is easy to understand that an organism or a chemical compound thus limited in its existence to the vegetative protoplasm of the plant might be very difficult to isolate. That growth disorders are not conveyed through the seeds may mean that the cause of the disease is too delicate or unstable to survive a resting stage. One of the growth disorders of cotton is limited to cool weather in the spring and fall. Malformations induced by chemical substances may be seen in the formation of galls through secretions or excretions of insects, mites, or nematodes. The growth disorders might be considered as slight, generalized gall-formations.

Investigators of animal nutrition now recognize special growth-controlling substances called vitamins and hormones whose absence or deficiency renders development abnormal, and results in such diseases of children as rickets, acromegaly, or cretinism. Some of the vitamins that are necessary for animals are derived from plants and may have their proper functions in the growth of the plants, so that plant disorders might result if the vitamins were destroyed or counteracted by other substances. Thus an anti-vitamin substance or a physiological disturbance that destroyed or disturbed the vitamin relations might be the cause of a growth disorder of a plant.

On account of the nature of the plant organization, growth is not restricted to one period, but is continued or renewed at intervals, so that a growth disorder is continued or repeated through the life of the plant individual. Thus it is possible to understand that such disorders as crazy-top may be similar to some of the diseases of children or of young animals. But until the causes of the plant disorders are more definitely known, investigation must be directed largely to the symptoms, as manifested in the behavior of the plants. Hence, a comparison of crazy-top with other growth disorders apparently is the best way to facilitate the further study that is needed.

GENERAL FEATURES OF CRAZY-TOP

Reference was made in the Journal of Heredity for October, 1923, to the crazy-top disorder in Arizona as possibly analogous to other growth disorders of cotton that have been studied in China and in Haiti. Further observations in Arizona showed additional features in common with the foreign disorders. As indicated by the popular name, the plants infected with crazy-top undergo a sudden change in their habits of growth, the upper growth of affected plants becoming abnormal and strikingly different from the earlier normal growth of the same plants. (See Pl. 2.)

The name *acromania* is suggested as a technical equivalent of crazy-top, conveying the same idea of abnormal behavior of the upper part of the plant.

Although the differences between the normal growth and the crazy-top growth are usually less striking than in the disorders in foreign countries, in other respects there are close analogies. After a period of normal development early in the season, the plant characters are changed abruptly and all of the later growth not only is abnormal, but shows many kinds and degrees of abnormality. The diversity of the affected plants renders it more difficult, of course, to recognize the disease, especially in scattered individuals, but when the crazy-top plants occur in large groups or areas there seldom is any difficulty in distinguishing the normal from the abnormal individuals.

One of the most general and striking features of crazy-top in Pima cotton in Arizona is the change in the form of the branches at the top of the plant, which suggested the name of the disorder. The upper branches of the affected plants usually are stronger and more upright than the normal horizontal fruiting branches developed from the lower joints of the same stalk (Pl. 2). The abnormality may be considered as a suppression of fruiting branches, or as a partial transformation of fruiting branches into vegetative branches. The transformation usually is not complete, as shown by the presence of a small floral bud or bud-scar at each joint of an abnormal branch. Some of the plants abort their buds at very early stages, as indicated by very small bud-scars, while other plants develop their buds nearly to the flowering stage before shedding. The abnormal branches also show frequent examples of fasciation or adhesion, where the branches divide but the bark remains united.

The sterility of the crazy-top plants is the feature of most interest to the farmer. Not only the abnormal upper branches are sterile, but usually the whole plant. (See Pl. 2.) A general shedding of buds and young bolls is considered by S. H. Hastings as the first symptom of an outbreak of the disease. This would explain why the normally formed lower fruiting branches are so generally sterile on the crazy-top plants, though sometimes a few bolls are retained. The extent of shedding may depend upon the conditions at the time of infection, or the injury might not become apparent until stress conditions were encountered. Of course, the symptoms are more striking and the losses greater when the crazy-top plants are in large groups or areas.

If there are no bolls to open, the crazy-top areas show notable contrasts with the other portions of a field at the end of the season. (See Pl. 1.) Such contrasts are more striking in Upland cotton than in Pima because the Upland bolls are larger and the fiber is pure white, while the Pima bolls are smaller and more evenly distributed, and the fiber has a buff tinge. Also the affected plants of Pima are not so completely sterile, but usually produce at least a few bolls at the top of the plant late in the season. With favorable cultural conditions a few of the affected plants of Upland cotton may set bolls late in the season, though mostly very small and imperfect.

CRAZY-TOP MORE SEVERE IN UPLAND COTTON

In former years, when the Pima cotton was grown exclusively in the Salt River Valley, the crazy-top abnormality was considered by some as an indication that the variety was "running out," and even urged as a reason for planting Upland varieties. But with Upland cotton planted extensively in 1923, and crazy-top appearing in many of the fields, that explanation of crazy-top could no longer be maintained, although many of the growers did not recognize the disease in Upland cotton on account of the different symptoms.[2]

[2] In this connection it may be noted that the average yield per acre of Pima cotton in 1923 was the highest since the variety began to be grown commercially. Also a careful comparison of old and new seed stocks in 1922 gave no evidence to support the idea of running out. See Kearney, T. H. (*12*).

[3] Reference is made by number (italic) to "Literature cited," p. 827.

In some of the Upland fields the behavior of the affected plants is much more abnormal than with Pima. The size of the plants is notably restricted by the shortening of the internodes, and the leaves are dwarfed and distorted, as shown in Plates 10 and 11. Such deformities of the leaves apparently do not occur in Pima cotton, but are quite similar to the effects of the stenosis disease on Upland cotton in Haiti. That the same disorder might produce different symptoms, or that differences of susceptibility might be shown in the various types of cotton, had also been learned from the previous study of the cotton disorders in Haiti and in China. Hence it was possible to suppose that the same disease could be responsible for the abnormalities of the Upland varieties, as well as of Pima.

The leaf injuries of Upland cotton in China were less than those of Upland cotton in Haiti, but in both cases the Upland cotton suffered worse than the Sea Island. Pima cotton in China showed relatively little of the mosaic discoloration, and the leaves were not crumpled nor the internodes shortened as in the native Chinese varieties. But the Pima cotton in China lost most of its leaves from black-arm, as though the susceptibility to that bacterial disease had been increased by the growth disorder. The cotton that suffered worst from the growth disorder in China was the native Asiatic type, although an Indian variety of the Asiatic type with hairy leaves and stems appeared to be quite immune to the cyrtosis disorder (Pl. 8). Similar differences of susceptibility to growth disorders or mosaic diseases are known in other plants. Although the crazy-top disorder does not show the usual symptoms of a mosaic disease, since there is no definite discoloration of the leaves and relatively little distortion, other features are closely parallel.

OTHER GROWTH DISORDERS OF COTTON TO BE DISTINGUISHED FROM CRAZY-TOP

Since the present interpretation of crazy-top would not have been reached without a previous study of other growth disorders, a review of such information seems necessary to give a clear understanding of the distinctive features of crazy-top. In addition to the disorders studied in China and in Haiti, to which reference has been made, the symptoms of crazy-top may be confused with other disorders which are of common occurrence in the United States, as brachysm, tomosis, and hybosis. Two or more disorders often appear concurrently in the same plant, and to some extent one disorder may be induced or intensified by another, so that the symptoms are variously combined.

These maladies are described as disorders, rather than as diseases, because they are not of the same nature as the better known parasitic diseases of plants, caused by fungi or bacteria. Some of the disorders appear to be of the same nature as the so-called mosaic diseases of other plants which in some cases are known to be communicated by insects. Patch-work mottling of the leaf tissues with areas of darker and lighter green is a prominent feature in the cotton disorder of China, but does not appear in crazy-top.

BRACHYSM, OR CLUSTERING

The name brachysm has been applied to an abnormal shortening of the internodes of the fruiting branches of frequent occurrence in Upland cotton, and usually accompanied by malformations of the sockets where the pedicels of the bolls are inserted on the internodes of the branches. Instead of a separable joint between the pedicel and the internode there is a more or less complete fusion. Hence in brachytic varieties the abortive buds or young bolls are not shed, but remain attached to the plant, even after they become shriveled and

dry, so that brachytic plants are sometimes considered as diseased on this account (*5*).

As a morphological change, brachysm represents an acceleration or stepping forward in the course of development toward the fruiting stage, so that the normal differences between the internodes and the pedicels are reduced. It may be considered that the internode-pedicels of brachytic plants are formed by a process of metamer-hybridism, combining the characters of two successive structures that normally are distinct. In other words, there is a breaking down of the normal differentiation of the parts, or intermediate expression of the characters that are normally distinct, a type of variation to which the term metaphanic has been applied.

Other metaphanic variations may be seen in the leaves of brachytic internodes which often are reduced and partially transformed into involucral bracts. Also the formation of the bracts is often abnormal in brachytic varieties, some bracts being more leaf-like, while others may be reduced and variously united with the calyx.

Though brachysm is considered as a normal character of some of the Upland varieties, and such "cluster-cottons" may be very productive under favorable conditions, the brachytic habit is considered undesirable and to be avoided in breeding. The brachytic varieties generally are very unstable and the tendency to brachysm may be so intensified that many of the plants are completely sterile when cultural conditions are unfavorable. Thus brachysm reaches a destructive stage when the abortion of flower buds is increased, or is carried to the point of total abortion, resulting in complete sterility. This may occur in only a few individuals, or the sterile plants may be so numerous that the yield is greatly reduced.

Various degrees of the brachytic tendency are shown. Some varieties that are not usually brachytic may have, under some conditions, very short fruiting branches. From the same stock of seed many brachytic plants may appear in some places, while in other places no indications of brachysm may be shown. In the Durango variety brachytic plants occur frequently in some of the irrigated valleys of Arizona and California, but may be quite absent in fields grown in South Carolina or in southern Virginia from the same stocks of seed, and similar behavior in relation to brachysm is indicated in the Acala variety. Even on the same plant, it often happens that some of the fruiting branches are normal while others are distinctly brachytic. Such differences of behavior have not been explained, but in view of the fact now recognized, that branching habits may be changed by growth disorders, it seems possible that some occurrences of brachysm may be connected with crazy-top or other growth disorders. Some features of crazy-top are similar to brachysm, or to abnormalities of branching that are to be associated with brachysm (Pl. 4). The late-season fruiting branches of Pima cotton have the internodes very unequal, and the sockets of the pedicels defective, much as in cluster varieties of Upland cotton. (See Pl. 3.)

TOMOSIS, OR LEAF-CUT

The chief feature in tomosis is the mutilation of the tissue of the leaf, with irregular perforations or marginal erosions, accompanied by more or less crumpling or other distortion (Pl. 5). The mutilations result from the death of portions of the leaf-tissue at early stages of growth. The dead areas are more frequent along the folds midway between the principal veins or along the margins, but may appear in any part of the leaf, and often with partial healing or regenera-

tion of the edges of the wounds. Adhesions may be formed in the scars and are the cause of some of the distortions of the mutilated leaves.[4]

Tomosis is of general occurrence in all of the cotton-growing districts of the United States, as well as in foreign countries. Though extensive tomosis injuries are usually confined to the seedling stage of the plants, a few injured leaves are usually to be found at later stages of growth. Occasional individuals show many tomosis mutilations through the season, and such plants are likely to be sterile or abnormal in other ways. Similar cases of congenital tomosis are likely to be found in hybrid stocks as one of the abnormalities that appear in the second and later generations. Also it appears that tomosis is more frequent in plants that are affected with other growth disorders than in normal plants under the same conditions.

The death of the leaf-tissue in tomosis has been traced to the oil-glands, which apparently are killed in advance of the neighboring cells. Under the microscope it is possible to see that the cells around the oil-glands are injured before they are killed. The chloroplasts become discolored and then disintegrate and disappear, leaving the cells transparent. Along the edges of the wounds some of the injured cells survive, but with no green color, the loss of the chloroplasts being permanent (Pl. 5, B, C, D). The injury to the chloroplasts suggests an analogy with the mosaic diseases, though the course of the disease is very different. The tomosis injuries are much more acute but more definitely limited, and with no subsequent weakness around the injured areas of leaf-tissue.

Though tomosis is very frequently accompanied by another disorder called hybosis, or leaf-curl caused by plant lice, which also affects cotton in the seedling stage, tomosis injuries may be severe where there are no plant lice, and no relation to other insects has been found. That the occurrence of tomosis is so general in itself is a reason for supposing that the injuries are not due to a parasite but are a general effect of some unfavorable condition, such as the wider and more sudden changes of temperature to which the young plants are exposed during the early stages of growth.

When tomosis is severe the growth of the seedling is retarded, and the terminal bud may be aborted, so that the plants are crippled and deformed, and generally produce fewer bolls than their normal neighbors. Except in these cases the effects of tomosis appear to be strictly temporary. Though all of the plants in a field may be badly affected, with the early leaves badly mutilated and deformed, such a period of distress may be followed by a general and rapid recovery with all of the new growth quite normal, as soon as the weather is favorable. (See Pl. 5, A.)

If the plants are not thinned too early the injured individuals are easily recognized and removed. Also there is less exposure to extreme conditions if the young plants are close together in the rows.

Tomosis occurs in all of the principal types of cotton, though some are more susceptible than others. In Arizona and California the Pima cotton usually is appreciably less susceptible to tomosis than the Upland varieties. Earlier recovery of Pima cotton from tomosis no doubt is connected with its ability to grow at lower temperatures. The Upland varieties remain dormant for a longer period while the weather is cold and also lose more time in the stage of susceptibility to tomosis.

With Pima and Sea Island varieties growing under the same conditions, at Sacaton, Ariz., the tomosis injuries of Sea Island cotton are more serious and

[4] COOK, O. F., LEAF-CUT OR TOMOSIS, A DISORDER OF COTTON SEEDLINGS (*4*). See also Reports of the Chief of the Bureau of Plant Industry, U. S. Department of Agriculture (*10, 11, 13, 16*). Cook, O. F., Results of cotton experiments in 1911 (*2*).

continue much later in the season, so that the plants may not recover in time to mature a full crop. The deformity and mutilation of the leaves were still severe in the Sea Island cotton after adjoining rows of Pima cotton had entirely recovered. Upland cottons also suffer severely from tomosis, and may be outgrown and outyielded by the Egyptian cotton, under conditions in the Southwest.

HYBOSIS, OR LEAF-CURL

The chief symptoms of hybosis are reduction and distortion of the leaves, but without the perforations or mutilations which are characteristic of tomosis. The two disorders are commonly found together on the same plant or on the same leaf, but may also occur separately (4).

The hybosis distortion is an upward swelling or crumpling of the tissue of the leaves, and usually is greater between the principal veins near the base of the leaf. The plant lice producing the injuries shown in Plate 6 were identified as *Aphis gossypii* Glover, a species that is widely distributed. Plant lice are regularly present with hybosis, and apparently are the cause of this disorder, though the extent of the malformations of the leaves depends upon the temperature as well as upon the presence of the insects.

The greatest malformations occur during the cool weather of the spring months, when the cotton is making only a slow growth (Pl. 6). As soon as the weather is warm enough for the cotton to grow rapidly the growth becomes normal. The altered behavior of the plants may be ascribed to the warmer weather, since the plant lice may still be present, though usually they become less numerous in midseason, and increase again in the fall. Also the hybosis symptoms return as the weather becomes cooler.

In some cases the recovery from hybosis is not uniform, and the growth of the plants in definitely restricted spots or areas may continue to show severe hybosis injuries while over the rest of the field the plants are producing normal leaves. Such irregularities were noted in fields of Pima cotton in the Salt River Valley, June 28, 1920, and a photograph secured which shows the extent of the hybosis deformity, continued later in the season than usual. No reason was found for the striking difference of behavior. The suggestion of alkali spots was considered, but seemed improbable. The possibility that such plants had been infected with crazy-top or some other disorder, which could intensify the hybosis effect, may be worthy of consideration.

The appearance of late-season hybosis in Mebane cotton at Sacaton, Ariz., in November, 1923, is shown in Plate 7. The internodes are much shortened and the leaves crumpled, though the size of the leaves and of the involucral bracts is not much reduced, and there are gradual changes from the normal to the distorted condition. Thus it is easy to distinguish the late-season hybosis from crazy-top, although from a distance the two might be confused. Hybosis is likely to be accompanied by tomosis, which is true also of crazy-top. The lacerated leaf at the lower right-hand corner of Plate 7 may be an example of tomosis, or possibly of insect injury. The plant lice were quite numerous on the specimen photographed, and of a very dark greenish color.

Hybosis is a prominent feature in the black-land prairie region of Texas, which is now the chief center of cotton production in the United States. The surface soil of the black-land prairies is likely to be wet and cold in the spring, and the growth of the cotton may be restricted for several weeks by a heavy infestation of plant lice, and the resulting distortion of the leaves may be very severe, though without a permanent injury to the crop. On the contrary, many farmers believe that it is good for the cotton to become "lousy" in the early stages. The restriction of growth early in the season is really an advantage under the black-land

conditions, since a larger growth of the plants would result in more serious checking by dry weather later in the season. Cotton that is planted on more open bottom-land soils often grows much faster and begins flowering much earlier, but is not so likely to mature a good crop as the cotton that grows on the heavy prairie soil.

According to reports from South Africa, serious injuries to cotton may occur from insects of the family Jassidae, with distortion and discoloration of the leaves, but later recovery of normal habits of growth in the dry season, when the insects disappear. Thus the jassid disorder in Africa seems most analogous to hybosis. Varieties of cotton with hairy leaves and stems are considered immune to the jassid disorder (*18*).

CYRTOSIS, OR CLUB-LEAF

This disorder is most severe in the Asiatic type of cotton, and is a limiting factor of cotton production over a wide region in the central part of China (Pl. 8). The disease apparently is of general and regular occurrence, with the late growth of all the plants affected. The development usually is normal to the flowering or early fruiting stage, with later abrupt transitions to the club-leaf condition. The leaves of the abnormal growth are reduced, distorted, and discolored, with mottling of dark and light green, especially along the margins and between the principal veins. The internodes and petioles are shortened, and small supernumerary branches are frequent, so that the abnormal growth may form compact masses of foliage, especially in the native Chinese cotton.[5]

When the disorder is severe all of the floral buds may be aborted, so that the crop is restricted to the early bolls. Cotton that is planted too late, so that bolls are not set before the cyrtosis begins, may remain completely sterile, especially under conditions of exposure to dry hot weather, which intensifies the cyrtosis symptoms. Thus the cotton suffers less from cyrtosis in the humid coast districts around Shanghai and Nantung than farther up the Yangtse Valley, at Nanking, Nanchang and Wuchang. In the more northern districts, from Hankow to Peking, there is less injury to the crop, on account of a later incidence of the disease.

In Upland and Sea Island cotton grown in China, cyrtosis does not shorten the internodes or reduce and curl the leaves to the same extent as in Asiatic cotton, so that the aspect of the affected plants is quite different. In Upland cotton the distorted leaves have the margins curled under (see Pl. 8, E), while in Sea Island cotton the margins are tilted up, so that the upper surface of the leaf becomes more deeply concave or channeled.

The occurrence in India of a disease that is closely similar to the cyrtosis disorder, if not the same, is shown in a paper by Kottur and Patal (*14*). It appears, however, from this account that the disease in India is of irregular occurrence, instead of being practically universal as in the cotton districts of China. This may indicate that most of the Indian cotton is immune to cyrtosis, or that the agents or sources of infection are less common than in China. The writers ascribe the disease to adverse conditions of growth, and state that it occurs much more extensively in some seasons than in others.

STENOSIS, OR SMALLING

The striking feature of stenosis is the extreme reduction in size that may take place in the internodes, leaves, and floral organs of the affected plants, in addition to deformity and discoloration of the leaves, as in the cyrtosis disease of

[5] COOK, O. F., A DISORDER OF COTTON PLANTS IN CHINA (*6*). See also Report of The Chief of the Bureau of Plant Industry for 1921, p. 23 (*17*).

China. The smalling disease was seen in July, 1923, in the vicinity of St. Michel, in the north-central part of Haiti. In some of the fields all of the plants appeared to be affected, while in other fields only scattered individuals showed the disease while the intervening plants had continued to grow normally through the season. In some cases it appeared that plants had become affected at different stages of growth, as indicated by the extent of the top-growth that had occurred after the incidence of the disease (*8*).

On account of the reducing effect of this disease in Upland cotton, the contrasts between the normal and abnormal growth are most striking. Also, there may be a very wide range of diversity in the abnormal growth of different individual plants in the same field of cotton, not only in the extent of dwarfing but in many other features of the abnormal growth, including the ability to produce flowers or bolls. The abnormal growth of many of the plants is completely sterile, either by suppression of flower buds or by abortion of the buds at very early stages. In other plants the flower buds may develop to larger sizes, or the flowering stage may be reached. Some plants produce many undersized flowers but set no bolls, or on some of the less injured plants bolls may be retained and grow to nearly normal size.

In the examples of stenosis shown in Plate 9 the abnormal growth began very abruptly, with the leaves and other organs suddenly restricted to very small size, after producing normal leaves at the lower nodes of the same stalks. One of the plants had grown less than three inches in height after the disorder began, though small branches from several nodes along the stalk showed the same dwarfing and other abnormalities as the top-growth. The other plant was less seriously affected, and retained its squares to larger size. The zigzag form of the stalk in this specimen is one of the many peculiarities that contribute to the diversity of the abnormal top-growth of the affected plants.

No indications of recovery from stenosis were observed, even in fields where the disease had remained limited to scattered individual plants that must have been infected several weeks before, as shown by the amount of abnormal top-growth that had developed. The absence of more recent infections would seem to show that the insects or other agents of infection were no longer present in the fields. Later plantings of Upland cotton, in July and August, 1923, were reported in November to have shown no indication of being affected with the disease.

The mosaic discoloration of the leaves, though generally appreciable in stenosis, is a less prominent feature than in cyrtosis, while the reduction or dwarfing of leaves and other organs is carried much farther, especially in Upland cotton. On account of the extreme dwarfing of the new growth in some of the affected plants, the range of variation in the symptoms appeared much greater in the stenosis disease in Haiti than in the cyrtosis disease in China.

The Sea Island type of cotton was represented by occasional plants in some of the fields and appeared to be much less affected than the Upland cotton, as had been observed also in China. The Bourbon or "Native Haitian" cotton did not appear to be injured at all by stenosis, though it may be tolerant of the disease, rather than immune. That the disease may be carried in the Bourbon cotton is indicated by a statement of G. G. Burlingame in April, 1924. A later planting of Upland cotton at St. Michel, Haiti, adjacent to a block of Bourbon cotton, showed a large proportion of diseased plants in the rows next to the Bourbon cotton, and gradual reductions in the number of diseased plants in the rows farther away.

DIAGNOSIS OF ACROMANIA, OR CRAZY-TOP

In Pima cotton the distinctive features of crazy-top are the abnormal branching and sterility of the affected plants. In Upland varieties the symptoms are more pronounced, including reductions and distortions of the leaf-blades, petioles internodes, involucral bracts and floral organs, with all stages of sterility from the complete suppression of the floral buds to the development of small unsymmetrical bolls. Under extreme conditions the reduction and distortion effects in Upland cotton may equal those of the stenosis disease in Haiti, but in Arizona the symptoms meliorate as the season advances, and the diseased growth becomes less abnormal. Thus flowering and fruiting may be resumed by many of the Upland plants before the end of the season, and in Pima cotton the production of late-season bolls on the abnormal top-growth is a regular feature.

When the leaves are reduced in size the lobes may be partially suppressed. The leaves may be aborted in the upper part of the plant while the floral buds are developed, or the leaves may be retained and the floral buds suppressed. The leaves are not discolored as in the mosaic diseases, and there is less tendency to crumpling or other distortion. Branching is very irregular, with fruiting branches largely suppressed or transformed into vegetative branches which also are very irregular in size. The involucral bracts are variously reduced or divided, the flowers often very small and the anthers defective so that pollen may be completely lacking.

ANALYTICAL SYNOPSIS OF GROWTH DISORDERS OF COTTON

Although crazy-top apparently is more analogous to cyrtosis and stenosis, the other disorders, brachysm, tomosis, and hybosis, are present in Arizona and need to be distinguished in the study of crazy-top. Hence the following synopsis is given in the form of an analytical key to assist in the study of the growth disorders and emphasize the contrasting characters:

Leaves not distorted, discolored, or reduced in size; malformations restricted to the fruiting branches, which have short joints more or less fused with the pedicels, so that aborted buds or bolls remain attached to the plant.....*Brachysm.*

Leaves distorted or discolored or the plants abnormal in other ways.....

Leaves with irregular perforations or eroded margins, resulting from death of portions of the leaf-tissue, beginning at the oil glands.....*Tomosis.*

Leaves not perforated or mutilated, except as tomosis may accompany other disorders.....

Leaves deeply crumpled or bullate by inflation of the tissue between the veins, resulting from the presence of plant lice in cool weather.....*Hybosis.*

Leaves not regularly bullate and the disease not restricted to plant lice or to cool weather, but becoming more severe with higher temperatures.....

Top growth abnormal, but the leaves not discolored.....*Acromania.*

Top growth abnormal and the leaves with mottled discoloration.....

Leaves of Upland cotton greatly reduced and distorted but not regularly or strongly discolored.....*Stenosis.*

Leaves of Upland cotton not greatly reduced but the margins notably discolored and strongly decurved or rolled under.....*Cyrtosis.*

It may facilitate the study of the growth disorders of plants to have general terms available as well as specific names for the various disorders. The word *dysphytis* might be used as a general term for growth disorders, with *dysphyte* to refer to a plant that is made abnormal by a growth disorder. No particular feature has been observed which is common to all of the growth disorders but

only the general feature that the growth of the plants is changed and becomes abnormal, yet this apparently is a sufficient reason why the different disorders should be associated at least for purposes of study.

CRAZY-TOP SYMPTOMS COMPARED

EFFECTS UPON THE SIZE OF THE PLANTS

The dwarfing effects upon the internodes, petioles, and leaf blades are less pronounced in crazy-top than in cyrtosis or stenosis, and the foliage retains a healthy green color to the end of the season. In Pima cotton the size of the plants is but little affected, except that the crazy-top plants often grow a few inches taller than the adjacent normal plants, as though sterility had given the affected plants a greater vegetative vigor. The appearance of the upper part of crazy-top plants is like some sterile hybrids or like the rank growth of "boll-weevil cotton" when all of the buds are aborted through weevil attack. The impression of greater vigor in the crazy-top growth no doubt is increased by the resemblance of the upright abnormal branches to the normal vegetative branches which are produced from the lower nodes of the main stalk on rank-growing, widely spaced plants.

In Upland cotton the effects of the disease may be much more pronounced, especially if the cultural conditions are not favorable for the plants or periods of stress are encountered. Near the center of the crazy-top spot, shown in Plate 1, some of the plants were quite stunted. This might result from earlier infestation of such plants when little of the normal growth had been formed, which no doubt would result in a greater restriction of later development.

ABNORMAL BRANCHING

The loss of the normal dimorphism of the branches, and the sterility of the affected plants are the most general as well as the most prominent feature of crazy-top. In Pima cotton the sterile crazy-top branches that replace the normal fruiting branches in the upper part of the plant are thicker and straighter than the normal fruiting branches and have an erect or ascending position instead of horizontal. Thus it could be said that formation of fruiting branches is suppressed by crazy-top, at least temporarily, during the period of stress or hot weather conditions.

In normal plants the two types of branches, fruiting and vegetative, are distinct, with definite functions and positional relations. The axillary buds produce vegetative branches, while the normal fruiting branches develop from extra-axillary buds, which stand at the right or at the left of the axillary buds. The abnormal branches that replace the fruiting branches and give the crazy-top plants of Pima cotton their peculiar and characteristic appearance are of intermediate forms, as sometimes occur in abnormal variations, like the so-called "bull-stalks" of Sea Island cotton, or in degenerate hybrids. Plants with such abnormal branches, intermediate between the vegetative and fruiting type, are often completely sterile, as a result of abortion of all of the flower-buds, usually at very early stages. Abortion of young fruiting branches was observed at Bard, Calif., several years ago and was considered an effect of over-luxuriant growth of the plants (*3*).

If growth continues on the lower fruiting branches of affected plants, abnormalities appear, like those of the top-growth. In some cases vegetative shoots are developed from axillary buds of the fruiting branch. In other cases the terminal portion of the fruiting branch changes its behavior, assuming the appearance of a vegetative shoot, and taking a more upright position, if the

weight is not too great to be supported. Abnormal supernumerary branches may also develop from axillary buds, though not to the same extent as in the cyrtosis disorder.

Floral buds continue to be formed on most of the abnormal crazy-top branches of Pima cotton, but usually the buds are aborted at very early stages, as shown by a small scar at the side of the leaf-axil. In other cases the transformation to vegetative branches apparently is complete, when no bud-scars are found and the stipular rims do not encircle the joints as in fruiting branches.

In Upland cotton greater changes occur in the branching habits, as in other features, as a result of crazy-top. In a field of Hartsville cotton near Casa Grande, Ariz., observed by Robert D. Martin in September, 1923, the fruiting branches were reduced to shapeless rudiments, and only a few of the affected plants retained any of their squares to appreciable size. Most of the squares were shed at very early stages of growth, and there were practically no flowers in the affected areas. (See Pl. 10 to 15.)

The later growth of the same plants, in October and November, was less abnormal. The fruiting branches were formed on most of the plants, though with very short, irregular, and abnormal joints. In November many of the plants were retaining their squares to larger sizes, though some of the plants failed to produce any squares or shed all of them in the minute rudimentary stages. Most of the squares were still being shed before flowering, though some plants were flowering and a few were holding some of their bolls. Thus there were many stages of sterility of the abnormal branches.

In Pima cotton the recovery of normal habits of branching is more general. Under less extreme conditions in latter part of season a more normal formation of branches is resumed. The buds are held, and a profusion of blossoms may give the crazy-top areas an appearance of fertility, but too late to make good the losses that have occurred. Most of the plants begin to set bolls, though inferior in size and with fewer seeds than normal bolls.

FASCIATION OR ADHESION OF BRANCHES

Fasciation or adhesion of branches is of frequent occurrence in plants affected with crazy-top. Examples of twinning or dichotomous divisions of the branches are not uncommon. The lower joints of such branches are often adherent at the base, and sometimes for the entire length of the joint, or the joints of several branches may be united. Adhesions between the internodes of the fruiting branches and the pedicels of the bolls are also very frequent.

Short axillary branches bearing a single boll on a long pedicel are often produced in Pima cotton at the upper nodes of the main stalk. In the crazy-top plants the long pedicel of this axillary boll often is more or less adherent with the basal joint of the fruiting branch. In such cases the axillary boll is usually abortive and the supporting branch may be dead although the fruiting branch is alive.

Many of the less abnormal branches that are formed at the top of the Pima plants late in the season are more or less fasciated or adherent, forming a rather dense cluster of leaves, flowers, and bolls, in contrast with the uniform open growth of the normal plants. Such clusters of small late bolls are found also in Upland cotton, but much less frequently than in Pima.

Fasciations or adhesions of large abnormal branches with main stalks of the plants were observed in a Pima field near Phoenix, Ariz., and noted as an extreme form of this abnormal tendency. In some cases the branch was nearly equal to the upper part of the main stalk and retained a nearly upright position, thus giving the appearance of a dichotomous division of the stalk. That such abnormal

growths represent transformed fruiting branches, rather than vegetative branches, is further indicated by the fact that they often have very long basal joints which is a character of fruiting branches, in contrast with normal vegetative branches which have short joints at the base.

SHORT AND IRREGULAR INTERNODES

Irregularity in the lengths of the internodes of the branches is a general feature of the abnormal growth. Instead of the normal gradation in the lengths of the internodes, an abnormal branch of Pima cotton had joints of the following proportions, beginning at the base: 7 inches, 3 inches, ¾ inch, 2¾ inches, 1 inch, ¾ inch. These irregularities were accompanied by twinning, adhesion, and irregular development of the secondary and tertiary branches.

In many cases the late growth, even from distinctly abnormal crazy-top branches of Pima cotton, shows a return to nearly normal forms of fruiting branches, with the basal joints longer and the others gradually shorter. At the same time, more normal fruiting branches are produced from the upper nodes of the main stalk. The production of more normal fruiting branches from the very abnormal "false vegetative" branches was noted as a further evidence of the general consistency of behavior in all parts of a crazy-top plant. While the habits of growth of the affected plants are distinctly abnormal the responses to differences of external conditions are as great or even greater than with normal growth.

The photograph of a late-season fruiting branch in Plate 3, illustrating a partial return to normal behavior in the late-season growth of Pima cotton, still shows very unequal joints and malformations of the sockets of the pedicels as in brachytic varieties of Upland cotton. The malformations of the sockets explain the failure to shed the abortive squares, as in "cluster" varieties of Upland cotton. That the dead and shriveled squares often remain on the affected plants has been noted by Dr. T. H. Kearney as one of the striking symptoms of crazy-top in Pima cotton.

The shortening of the fruiting branches was carried much farther in the Hartsville variety than in Pima, often to the extent of complete suppression or reduction of the branches to shapeless rudiments, less than an inch long (see Pl. 11 and 12). Even the more normal fruiting branches of Hartsville, formed late in the season, seldom had any of their internodes more than half an inch long.

The different degrees of shortening of the internodes determine the height of the affected plants and other differences in appearance that result from having the foliage dense or open. The shortening and irregularity of the internodes are features of crazy-top that should be considered in relation to the brachytic or "cluster habit" of some varieties of Upland cotton, as already noted in the review of brachysm.

ABNORMAL LEAF-FORMS

Reduction and deformity of leaves are not prominent features of crazy-top in Pima cotton, though often very distinct in Upland cotton, especially under stress conditions. Some of the distortion that occurs with crazy-top may be ascribed to tomosis, which frequently accompanies crazy-top, especially in Upland cotton, under adverse conditions, but the leaf-forms may be very abnormal with no indication of tomosis. It is only in extreme cases that the crazy-top deformities in Upland cotton may be equal or even greater than the cyrtosis deformities in China, though still exceeded by the injuries of Upland cotton in Haiti, associated with the stenosis disorder.

The extreme of crazy-top injury is shown in Plates 10 and 11 from a photograph of Hartsville cotton secured by Robert D. Martin in September, 1923, from badly affected areas that had been located by C. J. King in the field of Hartsville cotton near Casa Grande, Ariz. (See also Pl. 1.) At that time some of the plants had the leaves of the upper portion of the stalk reduced to mere rudiments or quite abortive. In that condition there was a notable similarity to the smalling disease in Haiti, as shown in Plate 9. The resemblance was recognized at once by A. T. Valentine, who reached Arizona in August after seeing the Haitian disease in July. Thus the similarity of the symptoms of the two diseases in Upland cotton led to a more detailed comparison of other features of crazy-top with the disorders that had been studied previously in Haiti and in China.

Even when there is little or no distortion of the crazy-top leaves in Upland cotton, the size of the leaves may be greatly reduced, and the form of the leaves may be changed by broadening and shortening of the lobes, so that the outlines are much more rounded. (See Pl. 12 and 13.)

Some plants have much less reduction of leaves than others, though the leaves are of simplified shape, with the lobes only slightly developed. On the other hand, some plants have leaves very small, but without showing any tendency to reduce or suppress the lobes. Hence it may be inferred that the size and the shape of leaves are separate "characters." In some of the late season growth as shown in Plate 14 the leaves are aborted, so that the top of the plant shows only bracts, or bracts and small flowers, sometimes in a dense cluster or a spike, with a complete absence of leaves.

With Pima cotton there is a less obvious change in leaf-forms, but small simple leaves, as shown in Plate 3, are of more frequent occurrence on small crazy-top plants, at least where growth is restricted by less favorable cultural conditions. Thus the restriction of growth and the reduction of many of the leaves to simple form is in common with Upland cotton.

LEAVES NOT DISCOLORED

The lack of mottling or discoloration of the leaves is a peculiar feature of crazy-top, in view of the similarity in other respects to mosaic diseases. Even where the affected plants appear stunted and show many deformities of the leaves or other parts, the foliage is not discolored, and the crazy-top areas appear darker than the rest of the field at the end of the season, possibly because the plants are sterile and the foliage does not ripen as on the normal fruitful plants. However, it is known that other mosaic symptoms may occur without mottling of the leaves. In a mosaic disease of the potato, as reported recently by MacMillan (*15*), the mottling of the leaves does not appear in plants that are grown at high altitudes, 8,000 to 8,500 feet, in the Rocky Mountains. The more intense sunlight of the high altitudes was found to be responsible for the disappearance of mottling, as proved by an experiment with plants grown in partial shade, which showed the usual discoloration of the leaves.

A recent account of a growth disorder of strawberries describes the leaves and inflorescences as greatly reduced and distorted, with no indication of mosaic discoloration, although under some conditions a marked reddening of the surfaces may appear. This disorder is supposed to be due to nematodes that are found in the terminal buds of the abnormal strawberry plants (*1*).

Though the color is not altered, the texture of the leaves in crazy-top appears to be slightly firmer and more brittle. A difference of behavior was noted by Robert D. Martin in crazy-top material collected and photographed in September and placed in water to keep fresh. It was noticed that the crazy-top growth did not revive, but soon shriveled and dried, although the stems were standing in

water and the normal foliage below the crazy-top growth revived completely and remained fresh for several days.

If any difference in color is to be detected, the foliage of the crazy-top plants appears to be darker or to hold its green color late in the season. The darker foliage could be considered as a result of sterility, rather than as a character of the disease, but confirms the absence of any mosaic effect. If a color difference had been shown the disease undoubtedly would have been considered as a mosaic as soon as its existence was recognized.

SHEDDING OF FLORAL BUDS

Abortion of the floral buds or "squares" is a feature of crazy-top, as of cyrtosis and stenosis, with the extent of abortion and the stage at which it occurs depending very largely upon the external conditions and also showing a wide range of individual variation among neighboring plants when the critical conditions are approached. All stages of sterility may be shown, from plants that shed all of their floral buds at very early stages through those that retain their buds to larger sizes, with some that produce flowers but fail to set any bolls and others that set bolls, but still differ in numbers and degrees of development attained.

Even at the end of the season when most of the plants are showing more normal behavior some individuals may remain completely sterile and fail to develop any of their squares beyond the microscopic or scarcely visible sizes. (See Pl. 12.)

ABNORMAL INVOLUCRES

Some of the crazy-top plants have very small involucral bracts, even on the buds that are retained to the stages of flowering and fruiting (Pl. 14). The marginal teeth of the bracts may be very small, or very irregular in size, or deeply split into three lobes, as in the abnormal involucres that are of frequent occurrence in brachytic varieties, representing intermediate stages between bracts and leaves. Some of the reduced bracts of crazy-top plants have only three teeth, like the small involucres of *Thurberia thespesioides*, a plant related to cotton, growing wild in the mountains of Arizona.

Involucres formed of a single empty bract, resulting from abortion of flower-buds at very early stages, occur frequently on the crazy-top growth of Pima and Acala cotton. Similar sterile involucres were abundant in weevil-infested fields at San Antonio, Tex., in 1921 (7). The production of such involucres was considered as an abnormal condition that might be due to persistent pruning of the floral buds by boll weevils, though it now seems possible that a growth disorder might be involved, in addition to weevil pruning. Other indications of a growth disorder in south Texas are reported in a recent letter from B. V. Hasselfield.[6]

[6] An extensive shedding of small squares at the U. S. Experiment Farm, San Antonio, Tex., is also reported by Robert D. Martin under date of June 19, 1924, with specimens of an insect that has been identified by the Bureau of Entomology as *Psallus seriatus* Reuter, the so-called "cotton flea." Most of the squares were being shed at very early stages of development, between 1 and 5 mm. in diameter, so that relatively few buds reached the stage of being infested by the boll weevil.

The popular belief in the relation of the "flea" to the shedding of the squares has been questioned because the insects are found where the severe shedding does not occur, and because shedding has continued where the insects have been kept away from the plants by cages. But, with a growth disorder, shedding would continue without the insects, or the disease might be absent while the insects were present. A disease conveyed by the "fleas" or other insects is indicated by the continued shedding of the young buds and the formation of many ablastic involucres, as observed at San Antonio in 1921; but the striking deformations of the leaves and branches produced in Upland cotton by the crazy-top disorder in Arizona apparently do not occur in Texas. For a disorder manifested chiefly by the shedding of the squares, *ablasty*, or square-drop, would be an appropriate name. More frequent over-wintering of infected cotton plants or native malvaceous weeds might explain the restriction of the disease to southern Texas, although the insect is more widely distributed. Such a disease may be preventable if the source of infection can be determined.

ABNORMALITIES OF THE FLOWERS

Most of the flowers that were produced on the late top growth of Hartsville cotton near Casa Grande were very small and the anthers did not open. Many of the anthers were shrunken, as though the pollen had not developed. A recent period of cold rainy weather might explain the failure of the anthers to open, but the failure of the pollen-grains to develop may be associated with crazy-top.

A case of complete sterility was observed in 1922 in the Coachella Valley, between Indio and Palm Springs, in a field of an okra-leaf strain of Acala cotton isolated by several miles from any other cotton, which may represent an analogous case of pollen-suppression by a growth disorder. A careful examination of many flowers in different parts of the field showed that no normal stamens were being developed, and that all of the anthers failed to open, although there were many flowers.

Earlier in the season a few bolls had been set on some of the plants, but widely scattered through the field. This might indicate that the disease began at the early flowering stage, or that some of the plants were not stricken as soon as others, as might be the case if a growth disorder were present. In view of the isolation of the field from other cotton any infectious disease must be supposed to have come from the native vegetation. A partial deficiency of pollen has been observed also in a planting of Acala cotton in another mountain valley near Palm Springs, confined to individual plants, which might result from a scattering infection with a growth disorder.

The reduction in the size of the flowers at Casa Grande was not regular, nor in definite proportion to other symptoms of the disease. In some cases rather large flowers were produced on badly distorted and reduced growth. Even on normal plants the size of the flowers may be somewhat reduced toward the end of the season.

DWARFING OF BOLLS

Though plants that are badly affected with crazy-top became completely sterile, under the stress conditions of the summer months, there is a partial recovery or mitigation of the symptoms under more moderate late-season conditions. In the crazy-top areas of the Hartsville field at Casa Grande only a small proportion of the plants recovered to the extent of retaining and developing bolls, and most of the bolls in such cases were very small and misshapen (Pl. 15).

In Pima cotton the late season return to a fruiting condition is more general and the bolls are more normal in shape and size, though fewer seeds are developed than in the late-season bolls of adjacent plants that are not affected with crazy-top. Data recorded by Robert D. Martin on numbers of seeds and abortive ovules of bolls from 25 crazy-top plants and 25 normal plants of Pima cotton, grown at the Sacaton, Ariz., seed-farm in 1923 are given in Table I.

Smaller numbers of good seeds were found in the bolls of the late-season crazy-top growth than in the earlier or mid-season bolls of the same plants, and both classes of bolls of the crazy-top plants had notably fewer seeds than the corresponding classes of bolls from adjacent plants not affected by crazy-top. The reduced number of ovules in the crazy-top bolls may not be significant, except as an indication that the ovules aborted at an earlier stage so that the rudiments did not persist in visible form in the mature bolls. Some of the "middle crop" bolls, though borne on apparently normal fruiting branches below the crazy-top growth, probably were produced during the crazy-top period, and thus may have shared any adverse influence of the disease.

TABLE I.—*Comparison of seeds per boll from crazy-top and normal plants at the United States Field Station, Sacaton, Ariz., 1923*

Bolls from "crazy-top" Pima plants							Bolls from normal Pima plants						
	Top crop bolls			Middle crop bolls				Top crop bolls			Middle crop bolls		
Plant No.	Good seeds	Aborted seeds	Total ovules	Good seeds	Aborted seeds	Total ovules	Plant No.	Good seeds	Aborted seeds	Total ovules	Good seeds	Aborted seeds	Total ovules
1	18	0	18	18	1	19	1	8	10	18	19	2	21
2	12	5	17	16	5	21	2	19	2	21	21	0	21
3	9	11	20	14	5	19	3	20	1	21	19	2	21
4	9	10	19	14	7	21	4	17	1	18	20	0	20
5	16	2	18	18	3	21	5	19	2	21	18	3	21
6	10	6	16	15	6	21	6	15	3	18	19	2	21
7	10	9	19	17	3	20	7	19	2	21	17	3	20
8	9	8	17	13	7	20	8	15	1	16	20	1	21
9	9	11	20	17	3	20	9	19	0	19	20	0	20
10	9	6	15	12	11	23	10	19	2	21	17	2	19
11	15	3	18	23	0	23	11	9	10	19	18	2	20
12	7	11	18	13	4	17	12	14	2	16	19	2	21
13	11	4	15	17	2	19	13	17	4	21	16	4	20
14	11	6	17	10	10	20	14	18	4	22	18	3	21
15	11	8	19	11	8	19	15	16	2	18	16	4	20
16	14	3	17	15	4	19	16	19	2	21	21	1	22
17	14	4	18	17	4	21	17	11	6	17	19	2	21
18	13	7	20	19	3	22	18	15	6	21	19	1	20
19	15	3	18	15	3	18	19	21	0	21	14	7	21
20	14	4	18	15	5	20	20	19	2	21	18	4	22
21	6	10	16	20	4	24	21	7	12	19	19	2	21
22	11	7	18	18	5	23	22	15	6	21	17	4	21
23	13	3	16	19	0	19	23	19	2	21	19	2	21
24	11	5	16	15	6	21	24	20	0	20	19	2	21
25	8	10	18	15	6	21	25	19	2	21	17	2	19
Total	285	156	441	396	115	511	Total	409	84	493	459	58	517
Average	11.4	6.24	17.64	15.84	4.6	20.44	Average	16.36	3.36	19.72	18.36	2.32	20.68

IRREGULAR OCCURRENCE OF CRAZY-TOP

The occurrence of crazy-top in the fields is as irregular as could well be imagined. Though a general tendency to appear in spots must be recognized, the margins of the spots are not definite, but show affected and normal individuals mixed indiscriminately in the rows. Isolated crazy-top plants may be widely scattered or in small open groups with normal individuals between. Striking contrasts appear between adjoining rows, when many plants in one row are affected with crazy-top and the next row is entirely free from the disorder.

If the soil or the cultural conditions were responsible for inducing the disease, more definite spots would be expected, with the marginal plants of the larger spots showing a series of gradations in the extent of reduction and deformity of the plants. Also some relation would be expected between the occurrence of the disease and the general growth conditions that determine the general size and vigor of the plants. But such relations are conspicuously absent. The occurrence of the disorder includes a very wide range of soil conditions, and plants of all sizes and degrees of vegetative vigor are affected.

The fact that badly affected individuals are so often scattered indiscriminately among plants that have continued the normal habits of growth through the season is also adverse to the idea of a resident cause of the injury located in the soil. It may be inferred from the failure to spread that the cause of the disorder, or the agency of distribution, operates in a very sporadic and temporary manner. Otherwise the infection would not remain scattered or sporadic but would be complete and continuous by the end of the season as was the case with

the club-leaf disorder in China, where all of the plants became affected in the latter part of the season, and all of the late-season growth was abnormal.

The irregular and interrupted distribution of crazy-top would seem to indicate that the disease is spread by insects or other agents that are not continuously present in the fields, or all of the plants would be affected, as in the cyrtosis disorder in China. The distributor may be active in the spring and fall but not in midsummer, as with the plant lice which cause the leaf-curl disorder.

In the Hartsville cotton field at Casa Grande some of the plants had been dwarfed at very early stages and were only 6 or 8 inches high at the end of the season. Around these were other badly crippled plants, but of larger size, 15 to 18 inches high. Finally, there were many plants that had grown to full size, with a height of 3 to 4 feet, and produced normal bolls, although the late-season top growth was definitely abnormal. Thus it seemed that three stages or periods of infestation might be indicated in this field.

The irregular mode of occurrence of crazy-top also appears inconsistent with the idea of genetic or physiological causes. A genetic defect would be scattered generally through the fields in the same way as other off-type individuals, or "rogues," while physiological effects would be expected to show more definite grouping and more continuous gradations, but the facts do not accord with either of these assumptions. While crazy-top appears under a wide range of conditions, there are many fields that show no crazy-top.

In order to test heritability of the disorder, seed was saved in 1923 from individuals having pronounced symptoms of crazy-top, and progenies are being grown in 1924. Also seed was saved from scattered rogues or off-type plants of the Pima, Acala, and Hartsville varieties, and the progenies are to be studied with a view to the possible relations with crazy-top.[7]

Of course it is not possible to have a clear understanding of the distribution and occurrence of such a disease until the causes are discovered, including the sources of infection and the insects or other agents for conveying the virus from one plant to another. The usual plant lice of cotton may be the conveyors of crazy-top, or leaf-hoppers, thrips, mites, or nematodes may be implicated.

CRAZY-TOP UNDER DIFFERENT CONDITIONS

The disorder is not restricted to a particular type of soil or to other special conditions, though the severity of the symptoms and the extent of injury depend largely upon the conditions. The occurrence of the disorder must not be confused with the extent of injury. If only the extreme cases were noticed one might suppose that the disease appeared only with bad conditions, but crazy-top plants are also found under the most favorable conditions, where the plants that are not affected show the most normal development and produce the largest crops. It should be remembered that shedding, sterility, and abnormalities of branching also occur in plants that are over-luxuriant; and that such symptoms may be induced by alternate checking and forcing of growth, as may occur in rich soils which are too heavy to take water readily or have too light a subsoil to hold water from one irrigation to another. Under such conditions the stalks may continue to grow though most of the fruiting branches are aborted.

If no extreme conditions were encountered, the recognition of such a disease would be the more difficult, since the effects might be limited to a slight depression or subnormal status of the affected plants, scarcely to be distinguished from

[7] A report from C. J. King, under date of June 12, 1924, shows that 132 hills were planted at Sacaton with seed from 14 crazy-top plants of Hartsville cotton, but only 3 hills germinated, all from the seed of one plant. Of Pima cotton, 140 hills were planted with seed from 13 abnormal individuals, and germinations were secured in 86 hills. Only 4 lots of the Pima seed showed no germinations.

the slight constitutional weaknesses, like those that may be detected when progenies are compared in plant-breeding work. With the existence of such disorders recognized, their relation to the problems of adaptation must be considered.

Though the occurrence of crazy-top may have no relation to the conditions that determine the growth and productiveness of the normal plants, it may be a serious factor in determining the values of varieties for purposes of production. The presence of a slight disorder, as of crazy-top in Pima cotton, under moderate conditions, might remain unrecognized, although rendering the crop much more sensitive to unfavorable conditions. The effects of the disorder would be considered as a character of the variety, which would appear less suited to cultivation, as when crazy-top was looked upon as a special weakness of Pima cotton. In the same way, it might be supposed that a field, or a farm, or a section of country was not well suited to cotton, while the crop in reality might be suffering from a growth disorder rather than from any unfavorable soil conditions.

If such a disease were carried over from year to year by survival of infested plants through the winter, the yields would be reduced and the necessity of a more frequent rotation with other crops would be inferred. The rotation might be desirable for other reasons, and less crazy-top might be encountered in a different field. It is reported that some of the worst cases of crazy-top have occurred on new land, but of course this does not prove that affected areas do not increase where cotton is grown continuously.

CRAZY-TOP IN DIFFERENT VARIETIES OF COTTON

The differences in crazy-top symptoms between the Pima and the Upland varieties are in line with what is known regarding the varied degrees of susceptibility of different types of cotton to other growth disorders. The theory that crazy-top is due to a special weakness or tendency to degeneration in Pima cotton must be discarded, in view of the fact that the Upland varieties are more seriously affected than the Pima, especially when grown under unfavorable conditions. The more extreme symptoms that appeared in the field of Hartsville cotton at Casa Grande have not been observed in Pima.

Near Phoenix, Ariz., the symptoms of crazy-top were observed in adjacent plantings of Pima and Acala, under conditions of luxuriant growth, and there the disease reactions were more similar than would be inferred from the contrasts that had been shown between Pima at Sacaton and Hartsville at Casa Grande. The characteristic crazy-top symptom in Pima, the strong upright branches at the top of the plant, had appeared to be lacking in the Hartsville variety at Casa Grande, but was shown quite distinctly in the Acala at Phoenix, though somewhat less pronounced than in the adjacent Pima rows. In this planting of Acala the growth of the main stalk was but little restricted, and the tendency to reduction and distortion of the leaves was much less apparent than in the Hartsville planting at Casa Grande, though in some plants it was definitely shown. Also many of the Acala plants had a tendency to abort the leaves near the top of the main stalk, thus forming tufts or spikes of very short branches bearing small squares, as shown in Plate 14.

Also there was noted in Acala the same tendencies as in Pima to transform fruiting branches into vegetative branches, or to develop vegetative shoots from axillary buds of fruiting branches, with or without suppression of the terminal buds.

In China the Upland cottons were more affected by the cyrtosis disorder than were the Egyptian and Sea Island cottons, but the native Chinese cottons, representing the Asiatic type, were more strikingly affected than the Upland

varieties. Yet one variety of Asiatic cotton, from India, growing at an experiment station near Wuchang, showed none of the club-leaf distortion, although the adjoining rows of native Chinese cotton were badly affected. This indication of the existence of an immune variety of Asiatic cotton is confirmed by information received recently from China by J. B. Griffing of Nanking University, with the photograph shown in Plate 8.

In Haiti the Upland cotton was more deformed by the stenosis disorder than Sea Island cotton. The so-called "Native Haitian" or Bourbon cotton showed no injury from stenosis, while the Upland cotton showed more serious injuries than from cyrtosis in China.

INDIVIDUAL DIVERSITY OF CRAZY-TOP PLANTS

A general impression of uniformity may be given by the reduced growth of the plants in a crazy-top spot, like that shown in Plate 1, but closer inspection shows many differences among the adjacent individuals, in the size, shape, and distortion of the leaves, in the occurrence of tomosis, in the shedding or retention of the squares, in the forms and positions of the involucral bracts, in the attainment of the flowering stage, and in the development of bolls. (See Pl. 2, 10, 11, 12, 13, 14, and 15.) The diversity may be comparable to that of a hybrid stock, or to the wide range of differences that sometimes appears in a stock that is being grown under new or unwonted conditions.

Many stages and degrees of abnormality had been observed in the Chinese mosaic disorder, and a still wider range of diversity among the affected plants was a feature of the stenosis disorder in Haiti, and a similar diversity appears in crazy-top. Though the individual differences are less striking in Arizona than in Haiti, they are obvious enough, especially in the Upland varieties, as will be seen from the photographs of a few examples, in Plates 10 to 15.

Such differences might be ascribed to irregularity of cultural conditions, but this view is not likely to be held when the differences that appear in adjacent plants in a crazy-top area are contrasted with the greater uniformity of the normal plants nearby. Little doubt will remain that the diversity of crazy-top plants is abnormal, as well as the particular changes of characters.

RELATION OF GROWTH DISORDERS TO HEREDITY

The individual diversities of plants affected with growth disorders show that many deviations from the normal hereditary course of development are induced. The normal characters are no longer brought into expression, but are replaced by aberrations or abnormalities of many kinds, differing among the types and varieties of cotton as well as among the individuals of the same stock. Different characters are shown, not because the plants have different conditions, but because development is disturbed by loss of the normal adjustments or expression relations that determine the characters or course of development of the individual. The changes of expression are somewhat definite, since otherwise the same aberration would not be repeated so consistently in the structural units of the individual plant, while neighboring individuals of the same stock show equally consistent expressions of other abnormal features.

Thus the growth disorders may be of special interest to students and investigators of heredity, as showing that the expression of the characters of plants may be changed by chemical compounds in a manner that may be analogous to the recently discovered control of development in animals by secretions of the ductless glands. Abnormalities that otherwise would be considered as aberrations of heredity become explainable as effects of poisons or of disturbances of the normal sequence in the chemical reactions that attend the process of development.

Even if organisms were found to be responsible for the growth disorders, the abnormalities would still be ascribed to the secretions or waste products of such organisms. Of course, it has long been known that insects could produce galls and other localized malformations, but in the growth disorders the whole subsequent development of the plant may become abnormal. Instead of a merely local irritation, as in a gall or a hexenbesen, the normal course of development may be lost suddenly, at any stage in the growth of the plant. (See Pl. 8, 9, 10, and 11.)

The growth disorders afford additional illustrations of the fact that two distinct processes are involved in heredity. The expression or development of the characters in the individual is distinct from the transmission of the characters. How the changes of expression are brought about is still unknown, but it is plain that expression can be modified, and in many different ways, by the growth disorders, and that the changes may be permanent during the life of the individual organism.

It has long been recognized that mutilations or defects induced by diseases are not inherited, but such accidental injuries are not the same as the changing of the course of development by the growth disorders, which continues through the life of the plant individual. Except that all of the later growth is abnormal, the changes of characters in crazy-top are similar to those that occur in "bud mutations," where single branches show changes of characters that are definite and can be propagated as a distinct variety. Also, in such cases the original characters are not lost, since reversions to the form of the original variety may occur in later bud mutations.

It has been customary to assume the existence of a "mechanism of heredity" to account for the very definite transmission of characters, but less consideration has been given to the idea of a mechanism of expression of the characters, as distinct from the mechanism of transmission. Definite ideas of such "mechanisms" are still lacking, but it is plain from the growth disorders that the control of development may be changed profoundly and in ways that may interfere quite definitely with the development of the individual, without corresponding changes of the transmitted characters. Though the causes are still unknown, the growth disorders undoubtedly have this remarkable property of interfering and altering the adjustment of the mechanism of expression.

Although the normal hereditary characters are thrown out of expression in the affected plants, they reappear in the next generation. The disturbing cause, that in some way prevents or masks the expression of the characters, apparently is not carried in the seed in most of the growth disorders, though some are difficult to distinguish from genetic defects. Yet the abnormal expression of the characters, as induced by the growth disorders, may go on indefinitely in the vegetative or somatic tissues of the plant, in all of the new growth that is formed. Some of the mosaic diseases are communicated readily by grafting or by artificial infection, as well as by insects or other natural carriers.

As yet there is nothing to show how the expression of the characters is deranged. Even the normal processes of growth are little understood, and we have no conception of what it is that controls the development of the plant and brings the normal inherited characters into expression. Though each of the growth disorders shows a general trend of abnormality in one direction or another, the greater individual diversity of the abnormal plants would seem to indicate a negative effect or loss of the normal adjustment of the expression relations of the characters, rather than a positive effect of establishing a new determination of the characters, although a certain stability is shown in the expression of the abnormal characters.

RELATION OF GROWTH DISORDERS TO COTTON BREEDING

The reactions of varieties to the growth disorders undoubtedly must be considered as factors of adaptation. Susceptibility or immunity to a disorder might easily determine the success or failure of a variety in any district or region of production. Some of the types apparently are completely immune to disorders that in other types cause extensive and destructive malformations.

The changes that may be caused in the characters and appearance of the plants by even the less serious disorders will need to be understood by those who take part in the breeding of varieties and the roguing of seed-stocks. The sporadic occurrence of such a disorder as crazy-top in scattered individual plants would give much the same impression as a mixture of varieties or a frequency of rogues or off-type plants, and might lead to the rejection of a superior seed-stock in the belief that it had "run out" or had been allowed to cross with other varieties. The growth disorders may explain why fields of cotton raised from the same stock of seed may sometimes show widely different degrees of diversity.

Other disorders may exist, less frequent or less definite than crazy-top, and bring serious complications into the work of the breeder. The occurrence of such disorders might be very irregular, not only sporadic as to place, but also intermittent in time or seasons. Conditions that had no relation to the growth of cotton might determine the existence of such diseases in malvaceous weeds or in other wild plants of adjacent lands, while other conditions would determine the presence or absence of insects to carry the disease from the native plants to the cotton.

In bulk plantings an intermittent growth disorder might be confused with a Mendelian recessive character, which would not appear in the first generation of a cross, but would recur in the second and later generations. A disorder that did not reappear in the second generation might be considered a mass variation. Such outbreaks of brachysm, fasciation, or leaf-deformities are sometimes reported, but generally are disregarded by investigators, for lack of any rational explanation. In selection and roguing work with cotton it has been observed that two or more of the off-type plants are likely to be found together or close at hand, instead of being scattered indiscriminately through the fields. While seeds of the same boll might remain together, such tendencies toward grouping of the abnormal plants should be considered as indications that growth disorders may be involved.

Study of aberrant plants that occurred in spots might lead to a recognition of other scattered plants as representing the same type of abnormality, allowance being made for the diversity that often exists among the individuals affected by a growth disorder. Also it is possible that growth disorders may have very mild or scarcely appreciable symptoms under moderate weather conditions early in the season, and that the serious distortion symptoms may appear abruptly at a later stage, when stress conditions occur.

SUGGESTIONS FOR FURTHER STUDY

With the recognition of crazy-top as a growth disorder, several new lines of investigation are suggested. The increasing substitution of Upland cotton for Pima in the Salt River Valley may facilitate the investigation of crazy-top, as well as increasing the importance of the disease, because the injuries are more severe in Upland cotton. Careful comparisons should be made where Pima and Upland cotton are affected by crazy-top under the same conditions. In view of the indications of more serious injury to the Upland plants, it is important to

determine whether the yields are reduced in Upland cotton to a greater extent than in Pima.

Locating and mapping of crazy-top areas would be desirable, to determine whether the disease recurs regularly in the same places. Also such localizing of the disease might lead to the discovery of native plants or weeds that carry the disease through the winter and serve as reservoirs of infection. There are many wild Malvaceae in Arizona, and crazy-top might not be confined to a single species. A wider range of host-plants is indicated for mosaic disorders than for fungous or bacterial diseases. The sugar cane mosaic is communicable to grasses of other genera, and an inoculation of *Nicandra physaloides* with the potato mosaic has been reported recently (*9*).

Insect carriers of the crazy-top infection might also be identified, if the disease were traced to wild plants, and such knowledge might make it possible to control the disease by removing the source or preventing infestation. On the other hand, if the sources and agents of infection are neglected, the disease may increase through the establishment of more centers of infection among the wild plants.

Over-wintering of crazy-top plants should be studied, to determine whether such plants survive and carry over the disease, whether the symptoms can be detected early in the season, and whether such plants are a factor in extending the disease.[8]

Fields that have had crazy-top injuries in previous years should be watched carefully to see if the beginning of the injury can be detected. It is believed by some observers that the onset of the disease is definitely indicated by the shedding of all of the squares and young bolls. Where abnormal shedding occurs with no apparent cause, the development of other crazy-top symptoms should be looked for, although it is possible that infestation may occur at earlier stages, and that the more striking symptoms are developed when stress conditions are encountered.

Early infestation may be indicated by different habits of growth of the plants or more gradual development of the symptoms, without the very abrupt change that apparently marks the onset of the disease in previously normal individuals. The occurrence of large numbers of such plants, though without the usual crazy-top appearance, should be studied with reference to early-season infestation of crazy-top, which might render the growth more consistent, without the abrupt changes that result from infection at later stages of development.

Cases of delayed recovery from the hybosis disorder have been noticed as occurring in groups or areas like crazy-top and possibly may be connected with early transfers of crazy-top infection from native vegetation by the plant lice. Also early infestation in Pima cotton may be indicated by plants of slender upright habit that often are completely sterile, although a few bolls may set late in the season. If early infections of crazy-top could be recognized and destroyed, protection might be secured against later spreading of the disease. Or if large areas are found to be affected, the cotton could be plowed up and the land used for other purposes.

[8] Persistence of the disease by over-wintering of affected plants was definitely shown in the Hartsville field at Casa Grande, visited May 27, 1924. The abnormalities of the new growth were as striking as those of the previous season, and appeared on many plants which had not shown the disease in the fall, along the margins of the affected area. In a field of Pima cotton near Scottsdale, visited May 29, the shoots of many plants also showed a definite reduction and cupping of the leaves, although the symptoms generally were much less pronounced than in the Hartsville field, and many of the Pima plants appeared normal. Crazy-top symptoms on seedling plants were first noted by C. J. King on June 11, 1924, in the Hartsville field adjacent to the diseased plants that had survived the winter. Since the field was being abandoned as unproductive, and was in a district well isolated from other cotton, Mr. King had arranged with the owner to try the experiment of over-wintering the diseased plants and of planting fresh seed in a part of the affected area.

Protection and shading of some of the affected plants would determine the extent to which the crazy-top symptoms are modified by the condition of growth and whether mosaic discolorations can be induced by shading, as in the case of the potato mosaic under high-altitude conditions. By means of insect-proof cages, the relation of the disease to insect carriers may be demonstrated, or plants inoculated artificially to study the conditions of infection.

CONCLUSIONS

Abnormal behavior of cotton plants, resulting in partial or complete sterility of the affected individuals, is of frequent occurrence in Arizona, and is known among the farmers as "crazy-top." The name *acromania* is suggested as a technical designation for the crazy-top disorder, both names alluding to the abnormal branching in the upper portion of the plant, which is a striking feature of this disorder. The recognition of acromania as a distinct disorder has resulted from previous study of other disorders which are to be compared and distinguished from acromania.

Crazy-top has been ascribed to exhaustion of the soil and to a supposed "running-out" of the Pima variety, but these theories are plainly inadequate. Although the crazy-top symptoms are more striking and the injuries are greater where the cultural conditions are less favorable for the plants, the disorder is not restricted to Pima cotton or to particular types of soil, or to lands that have grown cotton in previous years.

The crazy-top injuries are more severe in Upland cotton and the symptoms more numerous. In addition to the abnormal branching and sterility, as in Pima cotton, a wide range of diversity is shown in crazy-top plants of Upland cotton, with many forms and degrees of reduction and distortion of the leaves, involucres and floral organs. Also, the Upland cotton apparently does not recover or return to more normal behavior late in the season to the same extent as Pima.

The reduction and distortion of the leaves and complete sterility of the top growth in Upland cotton are similar to the cyrtosis and stenosis disorders in China and Haiti. Hence a comparison of crazy-top symptoms with those of other growth disorders, including the mosaic diseases, seems justified, although the characteristic feature of mosaic diseases, the mottled discoloration of the leaves, is not present in crazy-top. The less striking effects of crazy-top in Pima cotton, as well as the variation of symptoms and injuries under different conditions, also are paralleled in cyrtosis and stenosis.

Although the late-season growth of affected plants is less abnormal than the growth at mid-season, crazy-top apparently is a disorder resulting in permanent injury like cyrtosis and stenosis, instead of a disorder causing temporary injury like tomosis and hybosis.

The change in the branching habit results from the fact that the fruiting branches of the upper part of the plants are partially or completely transformed or replaced by vegetative branches. Partial transformation is the more frequent condition and is shown by the abortion of the floral buds at very early stages, leaving a minute bud scar on each internode of the branch.

Association of the crazy-top disorder with the mosaic diseases is suggested by the similarity of symptoms and modes of occurrence, and further knowledge may lead to the discovery of measures of restricting the injuries. The variable and sporadic occurrence of the disease may be explained if it is found that the infection is carried by insects from some of the native wild plants or weeds that are related to cotton. By determining the source of infection it may be possible to protect the cotton fields against the crazy-top disorder, or to avoid the injurious effects in other ways.

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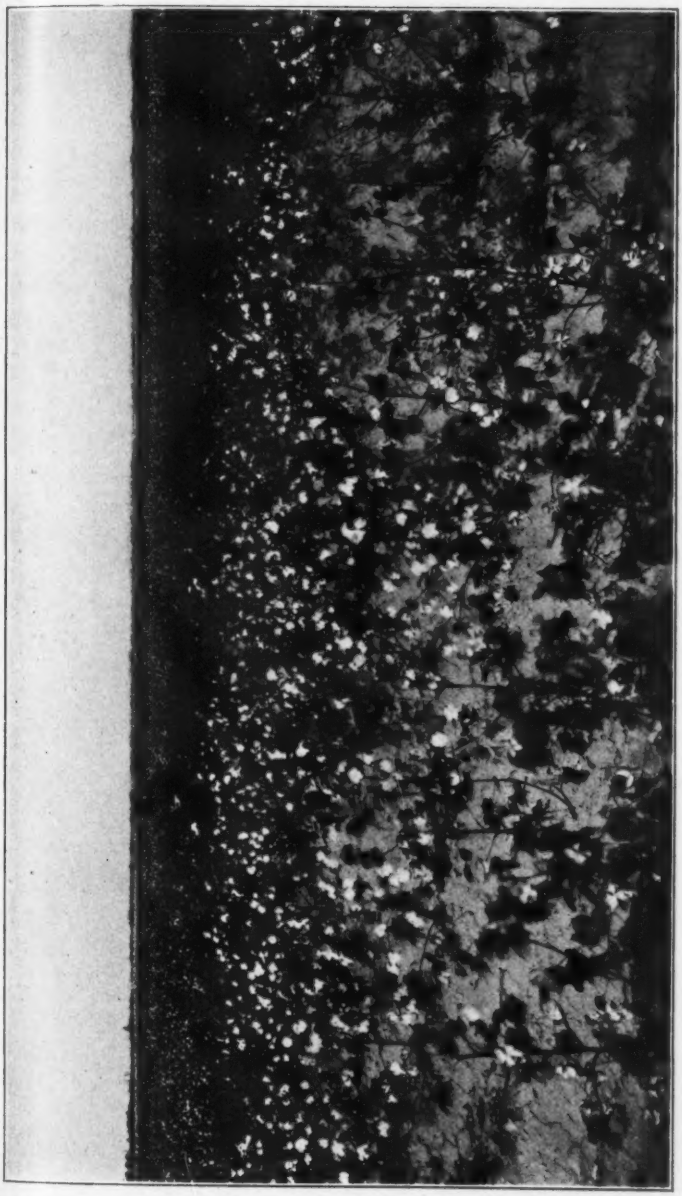
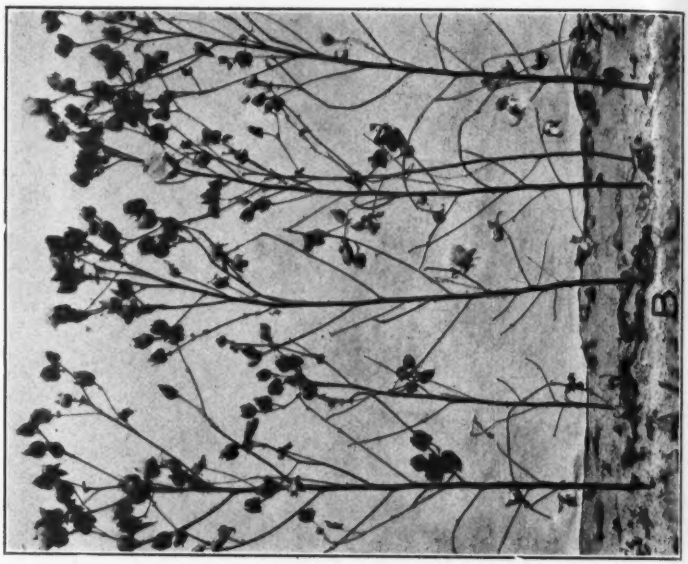
PLATE 1

An area affected with crazy-top in a field of Hartsville cotton near Casa Grande, Ariz., at the end of the season. The sterility of the crazy-top plants is indicated by the lack of open bolls in the affected areas. Also sterile crazy-top plants are shown at the right of the foreground.





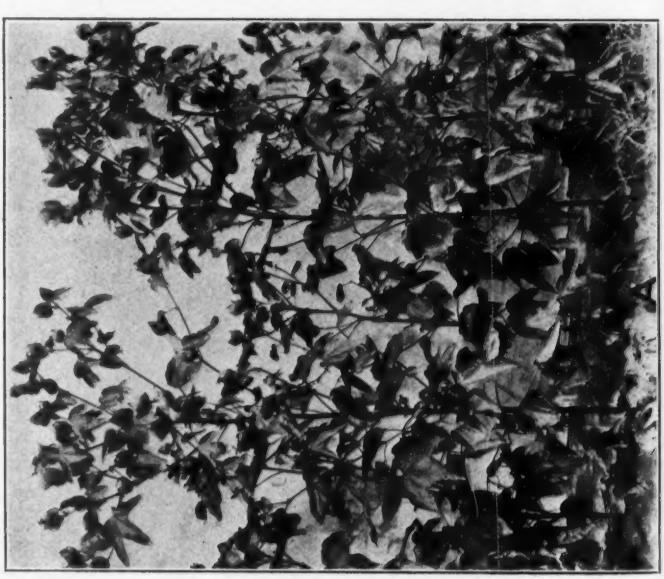


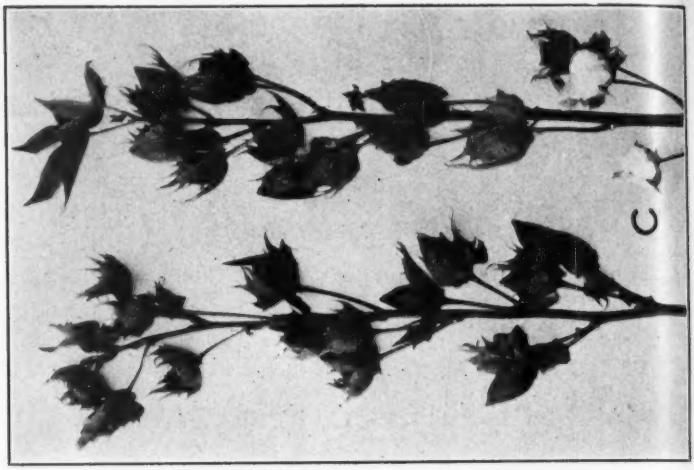
PLATE 2

A. Crazy-top in Pima cotton, showing the characteristic appearance at the end of the season, the plants sterile below but with an excessive top-growth of stiff erect branches, with numerous buds and small bolls, at the end of the season. To compare with Pl. 2 B.

B. The same plants as in Pl. 2 A, with the leaves removed, showing more clearly the characteristic ascending branches of the upper part of the plant, and the nearly complete absence of mature bolls on the lower fruiting branches. Photographed by Robert D. Martin, Sacaton, Ariz., September, 1923.

PLATE 3

Late-season fruiting branch showing irregular shortened joints, reduced simple leaves and small bolls, caused by crazy-top in Pima cotton.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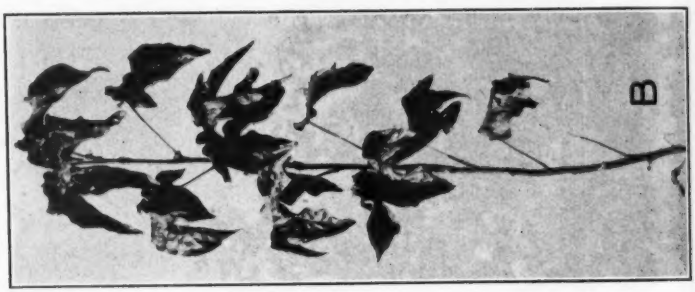
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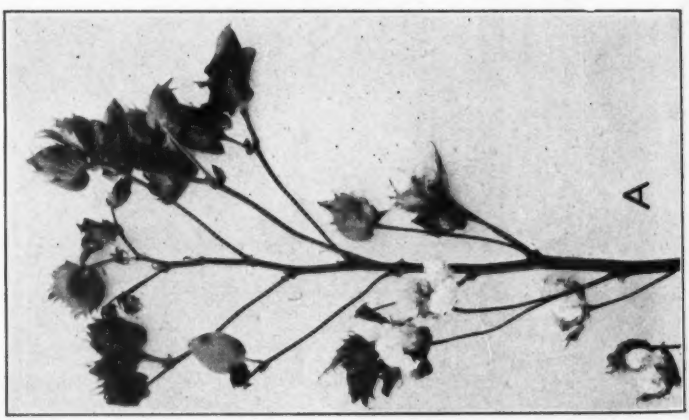
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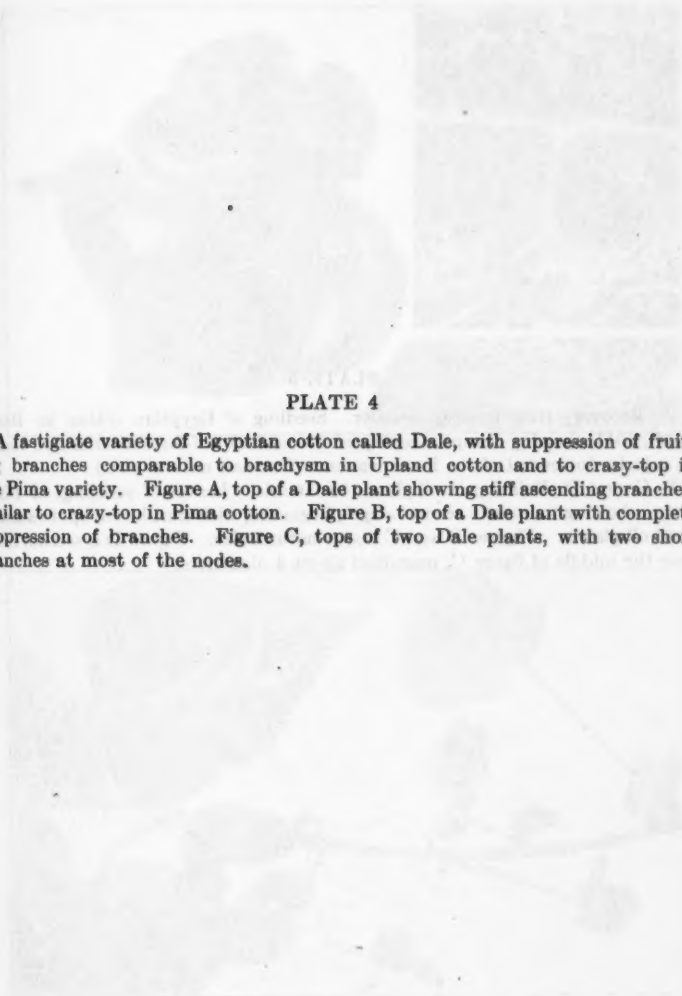


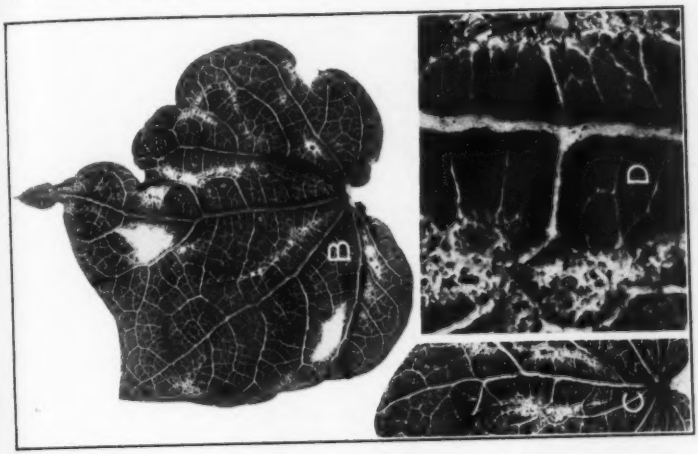
PLATE 4

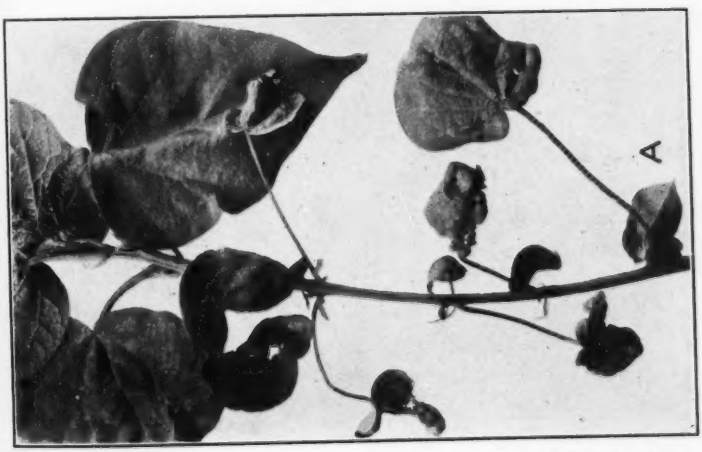
A fastigiate variety of Egyptian cotton called Dale, with suppression of fruiting branches comparable to brachysm in Upland cotton and to crazy-top in the Pima variety. Figure A, top of a Dale plant showing stiff ascending branches, similar to crazy-top in Pima cotton. Figure B, top of a Dale plant with complete suppression of branches. Figure C, tops of two Dale plants, with two short branches at most of the nodes.

PLATE 5

A. Recovery from tomosis disorder. Seedling of Egyptian cotton at Bard, Calif., 1911, showing abrupt recovery of the normal leaf-form after severe tomosis injuries to several of the lower leaves. (One-half natural size.)

B, C, and D. Relation of oil glands to tomosis. Leaves of seedlings of Pima cotton showing tomosis in several stages, beginning with translucent spots around dead oil-glands. Figures B and C about natural size. Figure D a section from near the middle of figure C, magnified about 4 diameters.


B
D


A

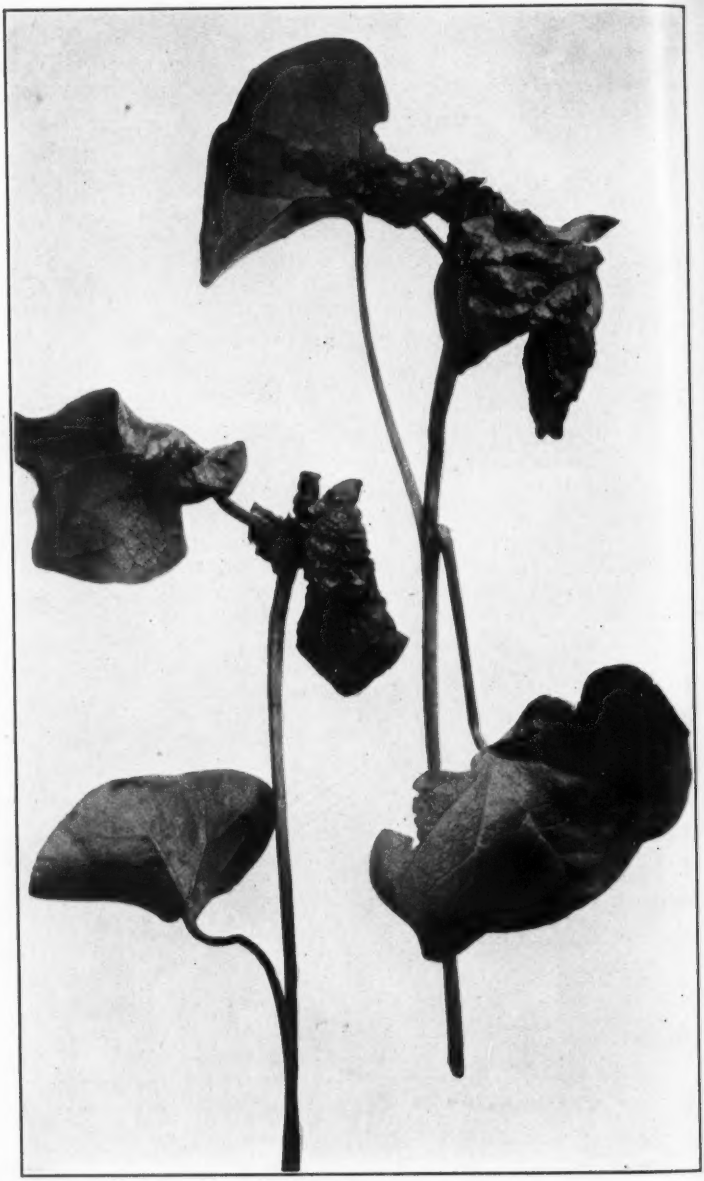


PLATE 6

Hybosis in Pima cotton. Seedlings of Pima cotton with the first leaves above the cotyledons badly crumpled and deformed, but not perforated or mutilated as in tomosis.

PLATE 7

Late-season leaf-curl (hybosis) of Upland cotton at Sacaton, Ariz., with shortening of internodes and crumpling of leaves, to be distinguished from crazy-top. (Natural size.)

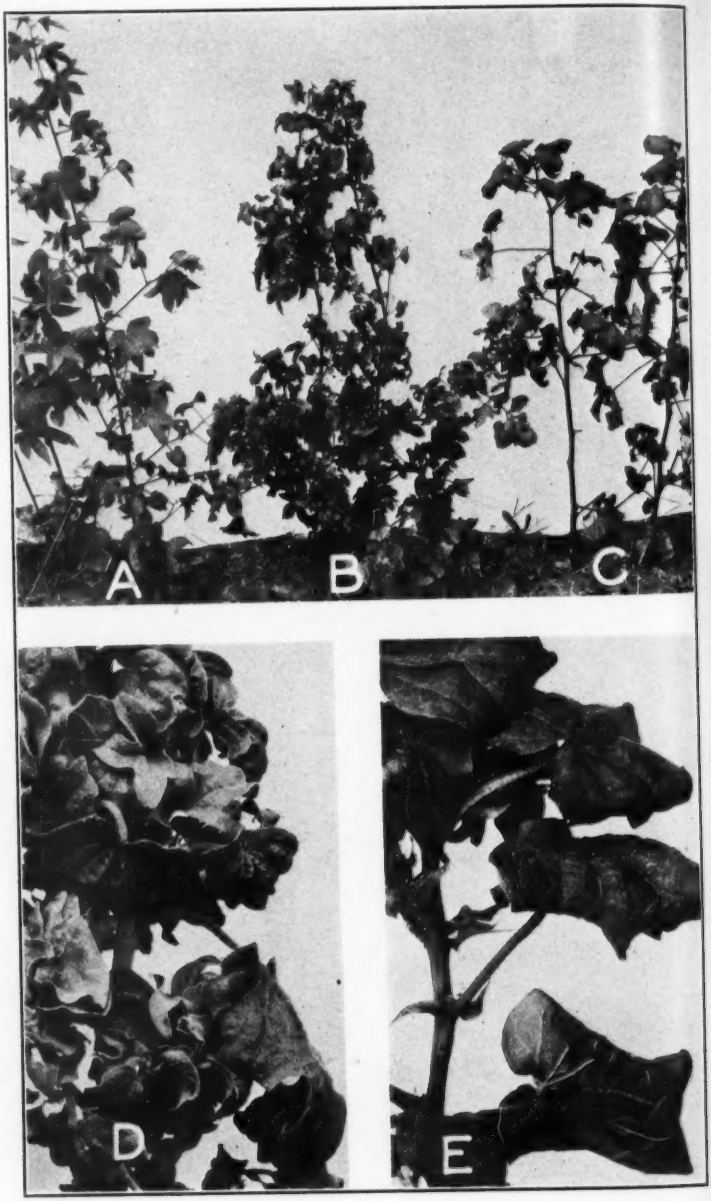

A
B
C
D
E

PLATE 8

Cyrtosis disorder in China. A, Asiatic cotton from India, resistant to cyrtosis. B, native Chinese cotton affected with cyrtosis. C, Durango cotton affected with cyrtosis. D, Chinese cotton affected with cyrtosis, natural size. E, Durango cotton in China, affected with cyrtosis, natural size. Figures A, B, and C, from photographs by J. B. Griffing, Nanking University, Nanking, China, October, 1923.

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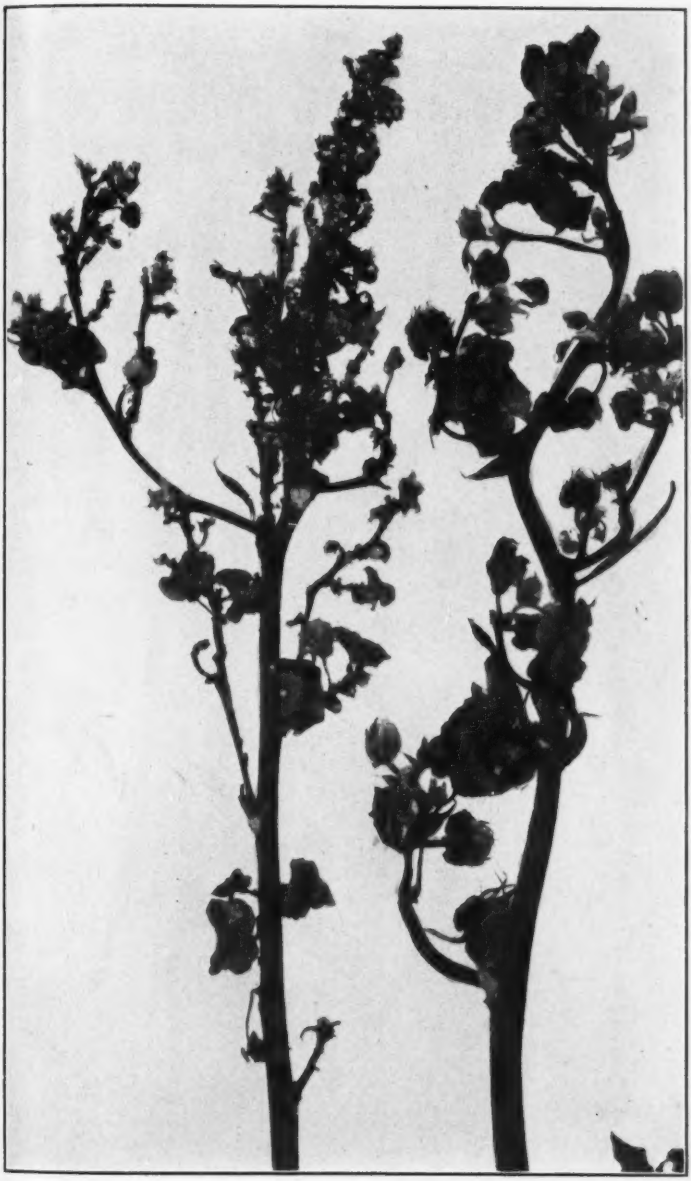
PLATE 9

Stenosis disorder in Upland cotton. Top-growth of two plants showing extreme forms of stenosis injury in Haiti, with abnormal branching, reduction, and distortion of leaves, and great diversity of affected plants, often with complete sterility in Upland cotton. To compare with extremes of crazy-top injury shown in Plates 10 and 11.



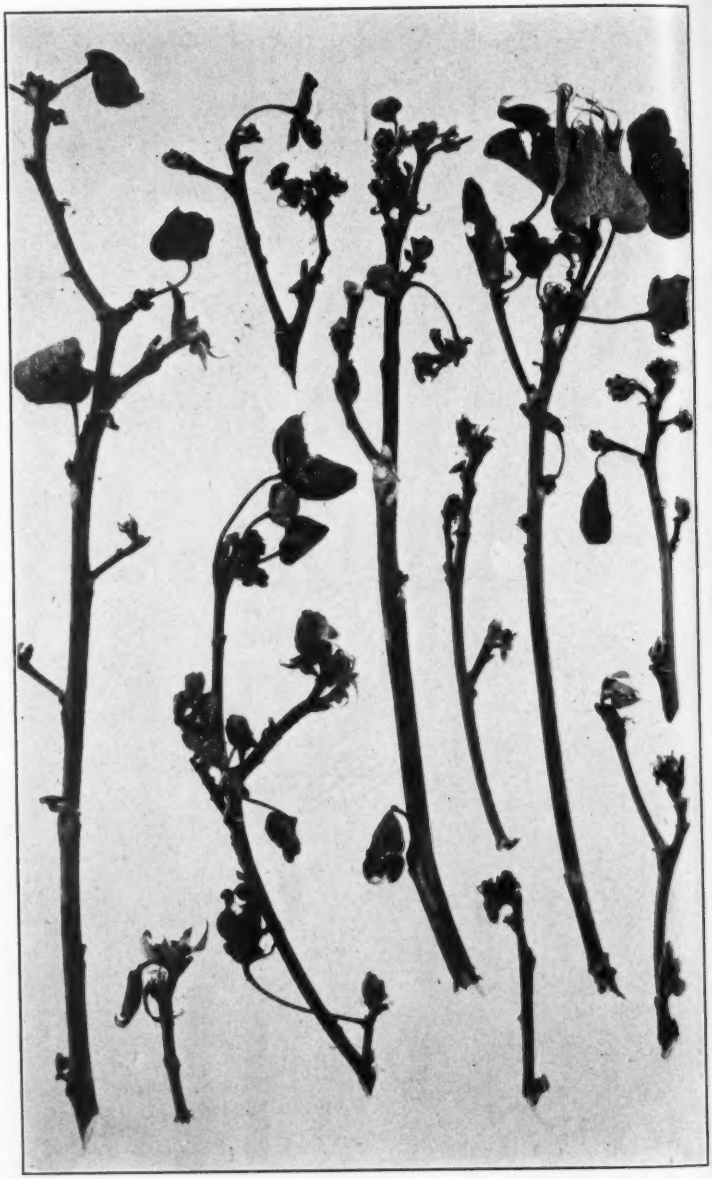


PLATE 10

Crazy-top in Upland cotton. Abnormal branches of badly affected plants showing extreme reductions and distortions of leaves of Hartsville variety at Casa Grande, Ariz., September, 1923. Photographed by Robert D. Martin. (Natural size.)

PLATE 11

Crazy-top in Upland cotton. Abnormal growth of badly affected plant showing suppression of fruiting branches and many stages and forms of reduction and distortion of leaves of Hartsville cotton at Casa Grande, Ariz., in September, 1923. Photographed by Robert D. Martin. (Natural size.)

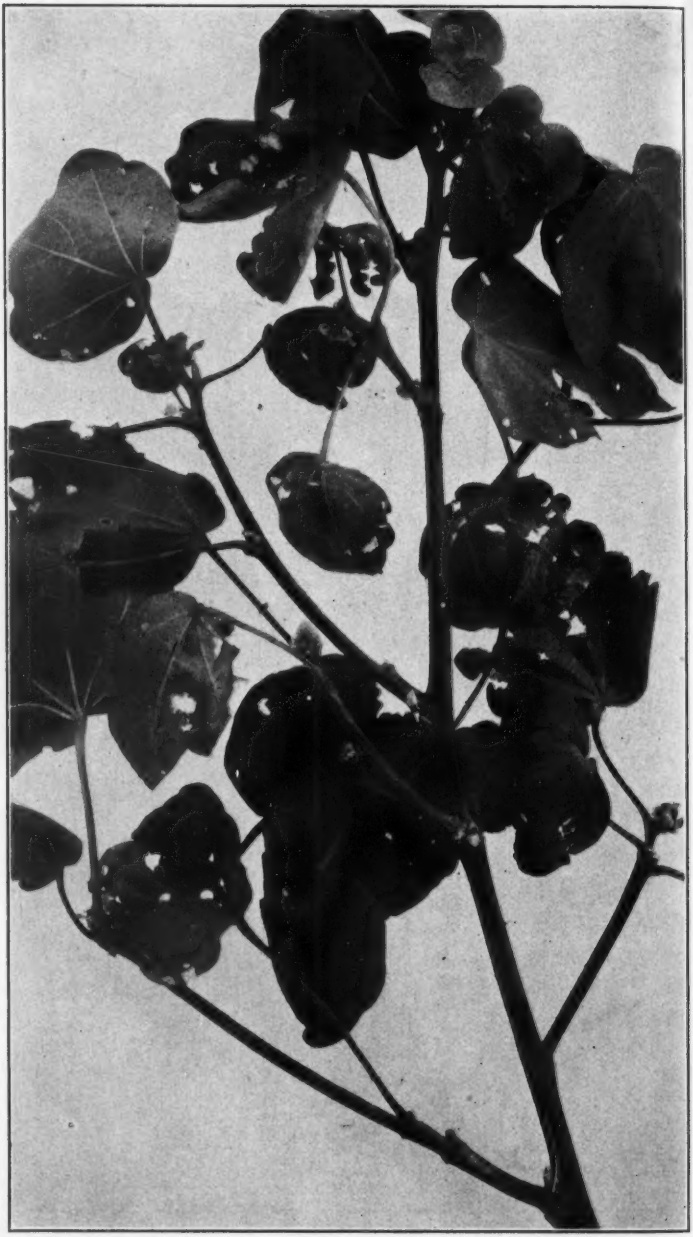


PLATE 12

Diversity in crazy-top plants. Top of a plant that was completely sterile, all of the flower buds being suppressed at very early stages, the leaves greatly reduced in size and with short broadly rounded lobes in comparison with Plate 13. (Natural size.)

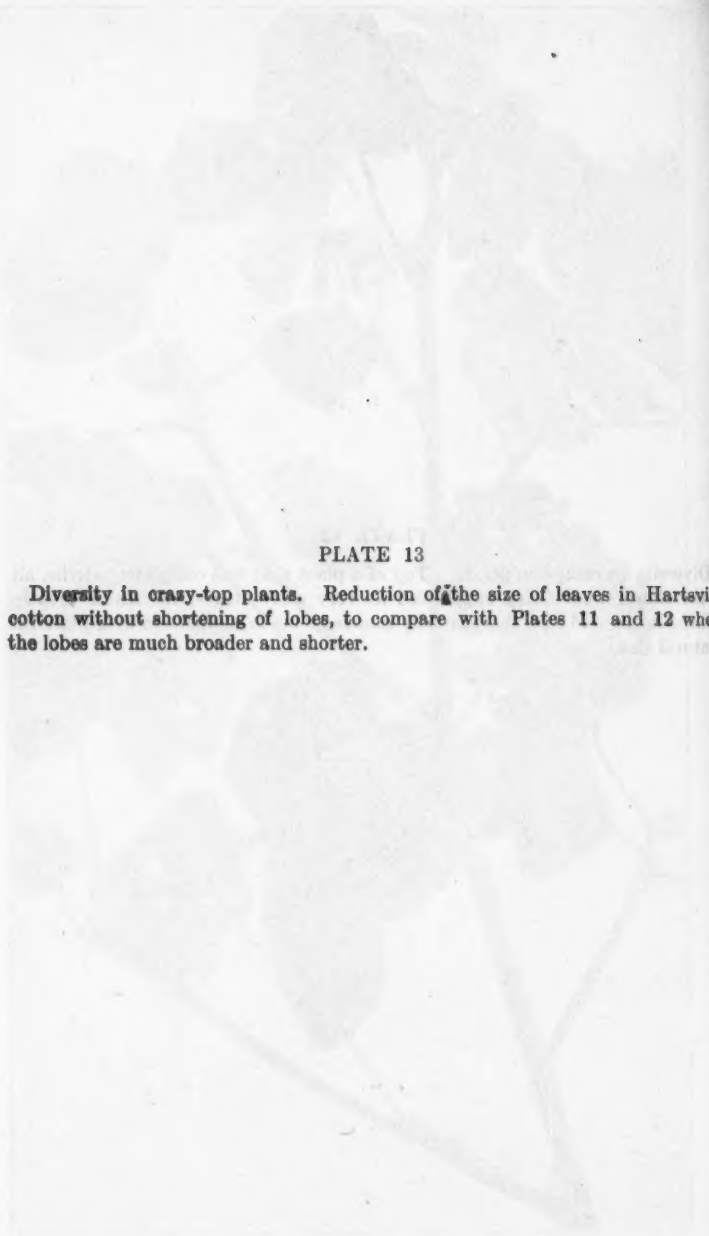


PLATE 13

Diversity in crazy-top plants. Reduction of the size of leaves in Hartsville cotton without shortening of lobes, to compare with Plates 11 and 12 where the lobes are much broader and shorter.

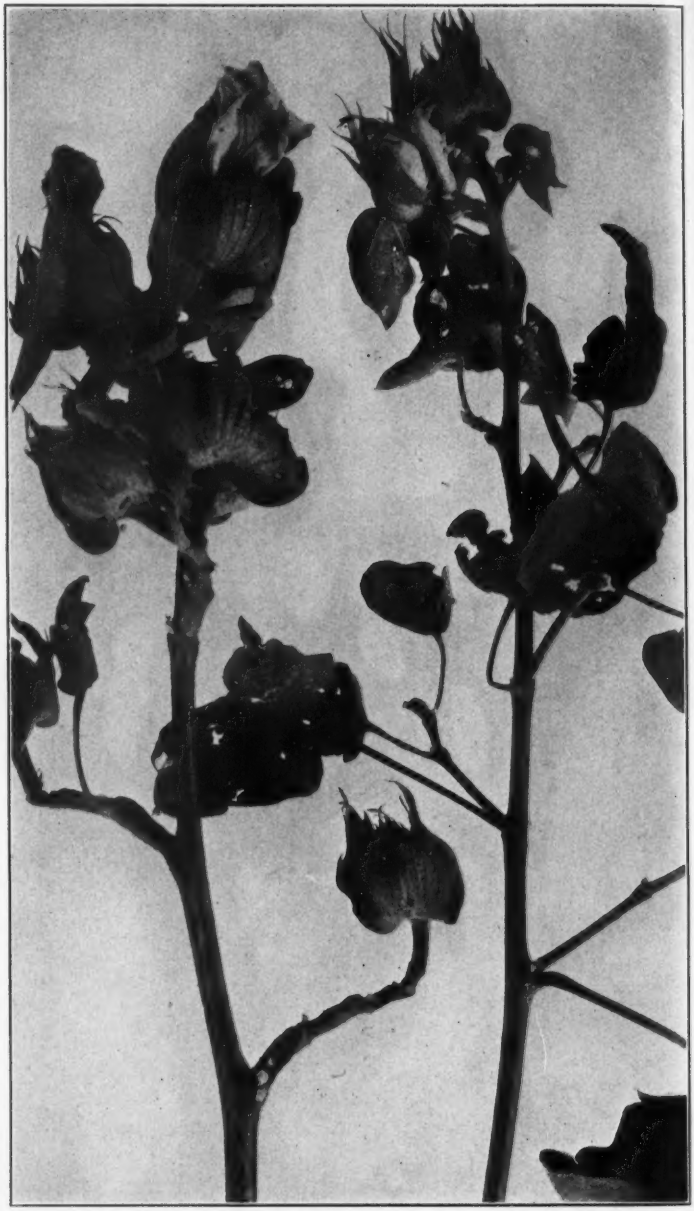
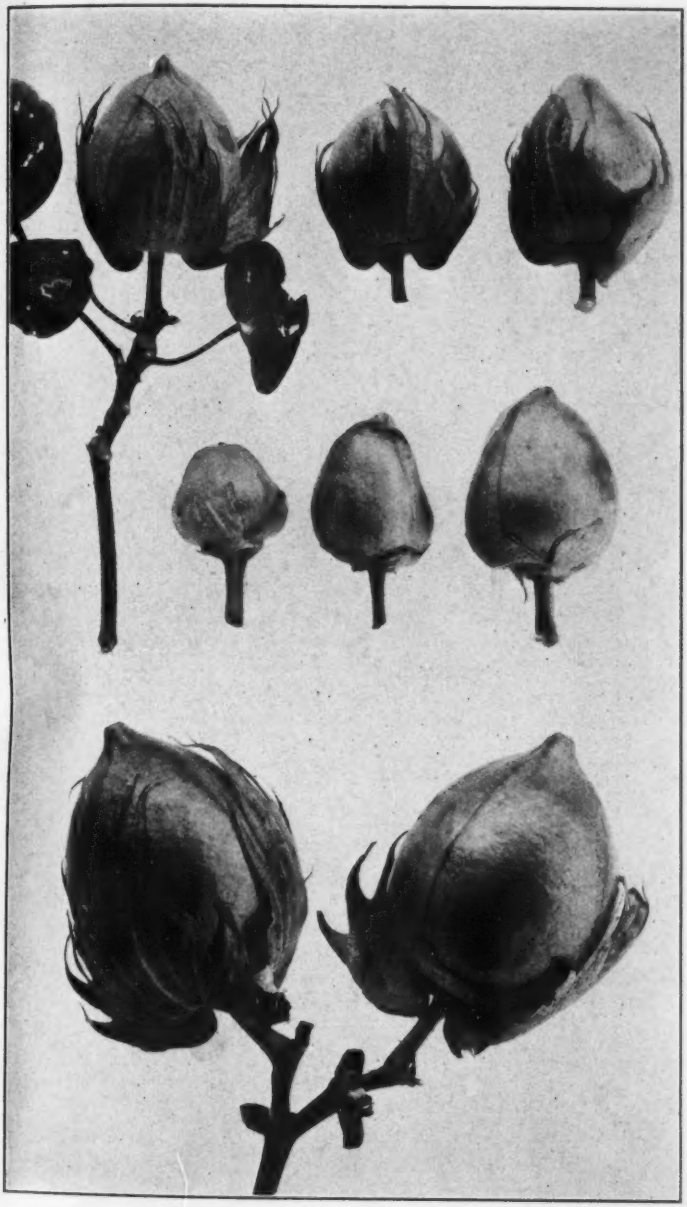


PLATE 14

Diversity in crazy-top plants. Upper portions of two affected plants, showing differences in the production of leaves, in the retention of floral buds, in the shortening of the joints of the fruiting branches, and in the shape and size of the involucral bracts. In some cases the flower buds are retained and the leaves suppressed, as in the left-hand plant, or the growth may be more compact, forming a rather close spike of floral buds with no leaves. (Natural size.)

PLATE 15

Bolls from crazy-top growth of Hartsville cotton, with normal late-season bolls of unaffected plants in the same field near Casa Grande, Ariz. (Natural size.) Most of the crazy-top plants shed all their flower buds or young bolls, but some of the affected growth produces small bolls at the end of the season.



THE POLYEMBRYONIC DEVELOPMENT OF PLATYGASTER VERNALIS[1]

By R. W. LEIBY, *Assistant Entomologist, North Carolina Agricultural Experiment Station*, and C. C. HILL, *Assistant Entomologist, Cereal and Forage Insect Investigations, Bureau of Entomology, United States Department of Agriculture*[2]

INTRODUCTION

In a previous paper the writers (*4*)[3] referred to the desirability of demonstrating insect polyembryony in a species in which but a few individuals are developed from a single egg. The development of such a species was in part described for *Platygaster hiemalis*, a parasite of the Hessian fly.[4] It was found, however, that polyembryony was carried only to the point where twin parasites were produced from a single egg, thus demonstrating the simplest type of polyembryony possible.

A slightly more complex form of polyembryony will be described here for *Platygaster vernalis* (Myers), another parasite of the Hessian fly, in which an average of about eight individuals are developed from a single egg of the parasite. A knowledge of the development of this species will furnish a further clue to the more highly specialized forms of polyembryony in which as many as 150 to 2,000 individuals are produced from a single egg.

Platygaster vernalis develops only in the mid-intestine of the host larva. The development of a closely related species, *Polygnotus minutus* Lindemann, which is also confined to the mid-intestine of the Hessian fly larva in France, has been described previously by Marchal (*5*). Marchal's paper upon this insect is now difficult to obtain. However, his paper does not treat of the precleavage or cleavage stages of development in a sufficiently detailed manner to demonstrate polyembryony, but it does describe quite fully the organogeny of the embryos. There are also some indications that *P. minutus* and *P. vernalis* differ slightly in the details of their development, although it is difficult to determine this definitely, because the development of Marchal's species is not illustrated with sufficient histological preparations. In the present paper, therefore, emphasis has been placed upon a study of microtomic sections, and the paper has been illustrated[5] from this viewpoint rather than upon gross examinations.

RELATION OF PARASITE TO HOST

The biology of *P. vernalis* with particular reference to its economic importance as a parasite of the Hessian fly, which is a serious pest of wheat, has been previously dealt with by the junior writer (*2*). The adults emerge from their

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[1] Received for publication April 22, 1924.

[2] The writers gladly acknowledge the continued interest shown by Dr. L. O. Howard and W. R. Walton in the studies reported in this paper. To Doctor Howard is due the chief credit for calling the attention of American investigators to insect polyembryony. Our studies on the development of the Platygaster parasites of the Hessian fly were initiated at the direction of Mr. Walton.

[3] Reference is made by number (italic) to "Literature cited," p. 839.

[4] *Phytophaga destructor* Say.

[5] All of the illustrations of microtomic sections except figures C and D on Plate 1 were drawn by the senior writer. The remainder of the drawings were prepared by the junior writer. The photomicrographs were made by the photographer of the Bureau of Entomology.

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cocoons (Pl. 1, E) during April and the early part of May. A group of approximately eight individuals emerge from each host puparium of the Hessian fly when parasitized by this insect. The female parasites, whether fertilized or unfertilized, deposit their eggs in the eggs of the host (Pl. 1, A, B) which are deposited on the wheat plants by the spring generation of flies. The parasite eggs begin development immediately (Pl. 1, C), the embryos being fully formed in the nearly mature host larvæ (Pl. 1, D) by the first of June. During June and July the parasite larvæ feed upon the contents of the host larvæ, each group of parasites devouring all of a host larva (Pl. 8, C) with the exception of its integument. After the parasite larvæ are fully grown (Pl. 8, B) they remain for some time in their cocoons which they have prepared inside the host larval integument. About the latter part of July the larvæ transform to pupæ (Pl. 8, D), these in turn transforming to adult parasites some time during August.

The adult parasites remain in their cocoons (Pl. 1, E) during the winter, being protected by the puparium or toughened integument of the host; and emerge from their cocoons and the host puparia in spring, by gnawing one or more holes through the cuticula and puparium of the host (Pl. 1, F). These adult parasites then search for eggs of the spring generation of the Hessian fly in which to oviposit.

PRECLEAVAGE DEVELOPMENT OF THE EGG

The eggs of *Platygaster vernalis* are always deposited singly, but occasionally a second or third egg may be placed in the same host egg by other females. However, the same female parasite usually avoids ovipositing in any host egg more than once. This parasite differs from *Platygaster hiemalis*, another parasite of the Hessian fly, therefore, in the number of eggs deposited at one time; *P. hiemalis*, as has been shown by the writers (*4*), placing a cluster of four to eight eggs in the host egg at each oviposition.

The egg of *Platygaster vernalis* is always so placed in the host egg that it is eventually found in the mid-intestine of the host embryo or young larva with unfailing regularity (Pl. 1, C). The egg does not and apparently can not undergo development in any other part of the host. The proper placing of the egg is doubtless accomplished by a complete coordination of certain factors, among which are the orientation of the host egg, the manner of striding the egg by the parasite, and the length of the parasite's ovipositor. It is of interest to note, on the contrary, that *P. hiemalis* always deposits its eggs in the host egg, so that they are never lodged in the mid-intestine, where apparently they would fail to develop.

THE NEWLY DEPOSITED EGG

The newly deposited egg is somewhat elongate, but it soon becomes more compact, cylindrical in shape, and rounded at both ends (Pl. 2, A), measuring, according to fixed and sectioned material, approximately 21 μ in length and 8 μ in width. The protoplasm of the egg appears very finely granular and uniform, and contains a spherical and darkly staining concentrated nucleus which measures 3 μ in diameter. Immediately after oviposition the nucleus is found in or near the center of the egg. The long and thread-like sperm (Pl. 2, B) is somewhat difficult to demonstrate in all eggs deposited by fertilized females, probably because of its wavy and spiral position in the protoplasm of the egg. There is also some evidence that not all eggs deposited by impregnated females are inseminated. The nucleolus or germ-cell determinant is wanting, just as it is in *Platygaster hiemalis*, and in *P. dryomyiae* as shown by Silvestri (*8*).

MATURATION AND THE ORIGIN OF THE PARANUCLEAR MASSES

In a general way the maturation of the egg of *Platygaster vernalis* is similar to that described for other species of Platygaster. As far as can be ascertained, it is identical in fertilized and unfertilized eggs. As in previously described polyembryonic and some monembryonic Hymenoptera, the polar bodies ar retained in the egg and eventually give rise to the paranuclear masses which have a nutritive function in the course of development of the embryos; while the oöcyte nucleus, whether fertilized or not, gives rise to the embryos.

The first maturation of the oöcyte nucleus is completed during the first eight hours after oviposition. Within the first 30 minutes the nucleus begins to expand, and by the fifth hour it is in the prophase stage of mitosis (Pl. 2, B, C). Thereafter maturation is completed quickly; the chromosomes being found first, grouped together at each end of the spindle but distinct from each other (Pl. 2, D), and then, later, somewhat concentrated into two separate nuclei (Pl. 2, E). The chromosomes of each of the two nuclei then condense further and form irregularly shaped, homogeneous, dark staining nuclei (Pl. 2, F, G), which are always quite conspicuous in the egg in spite of their small size. The first maturation takes place longitudinally in the anterior half of the egg, and results in the production of the first polar body, which passes to the anterior edge of the egg, and the oöcyte nucleus of the second order, which remains near the center of the egg.

Between the eighth and the twelfth hours after oviposition the first polar body and the oöcyte nucleus of the second order remain quiescent, but about the twelfth hour a second maturation of the oöcyte nucleus commences, and the mitotic division results in the production of two distinct groups of chromatin material in the central region of the egg (Pl. 2, H–J). The second maturation spindle is always considerably shorter than the first. Various stages of the division can be observed in eggs that are 12 hours old, indicating that second maturation is completed quickly. The anterior of the two centrally-disposed nuclei is the second polar body, which later migrates toward the polar or anterior region of the egg by the side of the first polar body. The posterior nucleus of the second maturation spindle becomes the female pronucleus of the fertilized egg or the cleavage nucleus of the unfertilized egg. It remains in the posterior half of the egg from the twelfth to the twenty-fourth hour, increasing in size during this interval from a diameter of 2.2 μ just after maturation is completed to 5.4 μ at the time of fusion with the male pronucleus.

About 24 hours after oviposition the two polar bodies begin to expand, becoming at first spherical and then oval (Pl. 2, K, L; Pl. 3, A, B), thus assuming the shape and appearance of typical paranuclear masses, as described for other polyembryonic Hymenoptera. As the polar bodies expand the chromatin breaks up into numerous small granules which are scattered throughout the plasm of each nucleus. As will be shown later, the polar bodies (henceforth known as paranuclear masses) migrate about in the egg and divide amitotically into similar secondary masses. It should be noted that simultaneously with the expansion of the polar bodies the egg increases in size, measuring in its greatest diameter when 1 day old approximately 28 μ in length and 9 μ in width.

FERTILIZATION

During the first six hours after oviposition the sperm transforms into an oval nucleus (Pl. 2, D, E), which is always located in the posterior region of the egg. A stage of the male nucleus is then evident, when the chromatin resembles a tightly coiled thread (Pl. 2, F). The threadlike chromatin next breaks up into

numerous pieces (Pl. 2, I), which are then distributed over a matrix (Pl. 2, G, H). Meanwhile, the nucleus has expanded until it measures approximately 5 μ in diameter. These changes undergone by the male nucleus are not always synchronous with the various stages of maturation but they take place between the tenth and twelfth hours after oviposition. From the twelfth to the twenty-fourth hours the male nucleus remains in a quiescent condition.

Fusion of the male and female pronuclei is effected about 24 hours after oviposition, in the posterior half of the egg (Pl. 2, K, L; Pl. 3, A, B). The egg now contains two paranuclear masses in its anterior region, and a cleavage or embryonic nucleus in its posterior region.

DIFFERENTIATION OF TROPHAMNION AND EMBRYONIC REGION

Shortly after the cleavage nucleus is formed, an area is seen to encompass it which is somewhat less dense than the remainder of the egg. This more lightly stained area is the embryonic region (Pl. 3, B), which together with the cleavage nucleus gives rise to the embryos. The remainder of the egg containing the two paranuclear masses constitutes the trophamnion.

The egg is henceforth properly known as the parasite body, for it now begins to increase in size. The active feeding of the host, which is soon to commence, permits the trophamnion to absorb the elements from the chyle in the host which are necessary for further growth. Similarly, the elaboration of the trophamnion and the distribution of the paranuclear masses within it are conducive to cleavage and the development of the embryos.

SUMMARY AND DISCUSSION OF PRECLEAVAGE DEVELOPMENT

In most respects the precleavage development of *Platygaster vernalis* is not unlike that previously described by the writers (*4*) for *P. hiemalis*, nor even greatly different from that described by Silvestri (*8*) for *P. dryomyiae*, which develops monembryonically. In *P. dryomyiae* the first polar body divides during the second maturation of the oöcyte nucleus, and the second polar body, produced at second maturation, unites with the posterior half of the divided first polar body to form one paranuclear mass; while a second paranuclear mass is developed from the anterior half of the divided first polar body. In *P. hiemalis* the writers have shown that the two polar bodies, resulting from the two maturations of the oöcyte nucleus, unite to form one polar nucleus, which later divides to form two subequal paranuclear masses. It has been shown above that in *P. vernalis* the two polar bodies neither divide (as they do in *P. dryomyiae*), nor unite (as in *P. hiemalis*), but that they develop directly by expansion into two subequal paranuclear masses.

If there is any significance in the fact that the first polar body divides before forming a paranuclear mass, or that the two polar bodies coalesce, or that they develop directly into paranuclear masses, it is not yet understood. In any event, the object accomplished is identical: paranuclear masses originate from the polar bodies, and are confined thereafter to a differentiated plasm of the egg known as the trophamnion. The function of the trophamnion is nutritive. It elaborates as the parasite body grows, and portions of it eventually surround each embryo of a polyembryonal mass, thus permitting each embryo to be so nursed that it can develop into a young larva. Henceforth the insect is able to provide for itself by direct feeding upon the host.

In other polyembryonic hymenopters Leiby (*3*) and the writers (*4*) have shown that the egg, before cleavage or very shortly thereafter, must be encompassed by host tissue in order to continue development. Eggs which are not so provided

cease development and become aborted. The egg of *Platygaster vernalis* is not encysted by host tissue, but is able to continue its development by reason of its location in the chyle of the host's stomach. The chyle, it should be recalled, is in reality the sap of the wheat plant, although it may be altered chemically by the nuclei of the intestinal lining; so that in one sense the parasite body may be regarded as developing in host tissue.

DEVELOPMENT OF THE PARASITE BODY IN THE HOST LARVA

The development of the embryos of *Platygaster vernalis* covers a period of about thirty days and takes place largely during the month of May, while the host larva is feeding and maturing upon the wheat plant. The presence of the parasite body in the stomach of the host apparently does not affect its growth. Like other species of polyembryonic parasites the *P. vernalis* larvæ are not developed to the point where they begin feeding upon the host until after the host is completely grown. Precocious development of the parasite larvæ, and feeding before the host is fully grown, would result either in their starvation or a reduction in the number produced from a single egg caused by the feeding of some of the parasites upon others of the brood.

The pupal and adult stages of the parasites are developed in individual cocoons (Pl. 1, E) formed by the larvæ in the carcass of the host during late summer. The adults remain in the cocoons during the winter and emerge the following spring.

EARLY CLEAVAGE AND THE FORMATION OF THE POLYGERM

About the second day after oviposition the cleavage nucleus migrates toward the center of the egg, where it divides to form two daughter embryonic nuclei (Pl. 3, C) of equal size. A second, third, and fourth cleavage of the embryonic nuclei take place between the third and sixth days after oviposition. These divisions of the nuclei produce parasite bodies which contain four, eight, and sixteen embryonic nuclei respectively (Pl. 3, D–F; Pl. 4, A). The embryonic nuclei are located in the central part of the parasite body in an enlarged embryonic region, which was differentiated around the cleavage nucleus when the parasite body was one day old. They are all of about the same size and measure approximately 4 μ in diameter.

While the first four cleavages take place, the trophamnion becomes elaborated proportionately. The earliest change is observed at the first cleavage, when one of the paranuclear masses divides to form two masses which immediately proceed to increase in size (Pl. 3, C). At this time the parasite body measures 24.3 μ in length and 10 μ in width. At the second cleavage four paranuclear masses (Pl. 3, D) are observed in the trophamnion. At the third cleavage there may be as many as twelve paranuclear masses. As is shown in Plate 3, E, the masses are distributed uniformly throughout the trophamnion. The parasite body now measures approximately 27.3 μ in length and 14.5 μ in width. Its form is still ovoid, and similar to that of the original egg.

The development of *Platygaster vernalis* reaches that stage which is comparable to the polygerm stage of other polyembryonic hymenopters at the end of the fourth cleavage (Pl. 4, A), at which time the parasite body contains sixteen nuclei in the embryonic region if all nuclei have divided regularly. Each embryonic nucleus then becomes separated from the others, and, surrounded by a bit of the embryonic cytoplasm, the cytoplasm with its nucleus becomes invested by a membrane. A cell is thus formed and recognized as a germ. The germ becomes the progenitor of one or two parasites, depending upon whether or not it divides once in the morula stage. The parasite body now represents a typical polygerm.

If all the nuclei divided regularly at the fourth cleavage the polygerm should contain sixteen germs. If only seven of the eight embryonic nuclei divided at the fourth cleavage, the polygerm would contain only fifteen germs. Difficulties of interpretation as to whether each germ is originally composed of a single cleavage nucleus are often encountered by reason of the fact that the single nucleus of a germ divides to form a binucleated germ before others of the same polygerm divide. Moreover, the nuclei are often so disposed (one above the other) and the germ membrane is sometimes so indistinct, that it appears as if some germs might originally be composed of two embryonic or cleavage nuclei.

The contention that a germ originates from a single embryonic nucleus in this polyembryonic species is based upon a study of such preparations as are illustrated by Plate 4, A and B. Figure A shows that most of the nuclei are each surrounded by a portion of the embryonic cytoplasm, which is in turn encompassed by a membrane. Figure B represents a later stage, and shows two germs containing but a single nucleus each, while two other germs contain two nuclei each as a result of a recent division of the original nucleus of each of the two germs. A fifth germ contains four nuclei, while a sixth has already advanced to the morula stage.

The polygerm is either slightly ovoid or spherical at this time and measures approximately 47 μ in its greatest diameter. The trophamnion now is no longer confined to the periphery of a central embryonic region but penetrates toward the center of the polygerm so that it surrounds each germ.

About the twelfth day the polygerm (Pl. 4, C) measures about 57 μ in diameter. With the increase in size of the polygerm there is also noted an increase in the size of each germ. At this stage certain of the germs divide in toto to form two daughter germs. Not all of the germs divide, and when division takes place the parent germ is usually composed of approximately eight nuclei. A similar division has been recorded by Marchal (*5*) in *Polygnotus minutus* and by the senior writer (*3*) in *Copidosoma gelechiae*. A typical case of germ division is illustrated in Plate 4, C. Here two of the four germs are daughter germs that are still in contact, and separated only by a very thin portion of the trophamnion which filtered between them immediately after division. Henceforth the embryos develop rapidly into the blastula stage.

THE POLYBLASTULA STAGE

About thirteen days after oviposition the parasite body (Pl. 4, E) represents a typical polyblastula stage. The germs have increased both in size and in number of their nuclei. The nuclei become lodged in cells and are arranged regularly in the periphery of the germ, so that a median section through an embryo illustrates a true blastula. At the thirteenth day the polyblastula measures about 55 μ in its greatest length and 45 μ in width.

Between the thirteenth and eighteenth days the polyblastula increases in size until it measures about 75 μ by 68 μ (Pl. 4, F; Pl. 5, A). The oval or spherical shape of the parasite body is maintained. During this interval the blastulas and the cavities in which they are found increase in size proportionately, as do the paranuclear masses of the trophamnion. The trophamnion also appears somewhat vacuolated.

By the twentieth day the polyblastula measures when spherical about 114 μ in diameter. At about this stage one observes definitely that all of the embryos are not approximately of the same size. Some of the embryos are normal blastulas, while others are composed of but four to ten nuclei and are in reality in the germ stage. Instead of the cavities in which the germs are located measuring 40 μ in diameter, as do those of the typical blastulas of this age, they measure

only 18 μ in diameter. Two such germs are represented in the polyblastula illustrated in Plate 5, B. These germs have failed to develop, and will degenerate. They are similar to the pseudogerms described by the writers (*3*, *4*) in *Copidosoma gelechiae* and in *Platygaster hiemalis*. Pseudogerms apparently do not occur in all *P. vernalis* parasite bodies. The writers believe that they are developed as a result of total division of a daughter germ, and that the resulting components do not contain sufficient potential elements to allow them to mature.

At about the twenty-fourth day the polyblastula is usually elongate. The one represented by Plate 6, A, measures approximately 0.4 mm. in length and 0.07 mm. in width. It contains seven blastulas which are about ready to begin organogeny of the embryo. In this particular parasite body the paranuclear masses are found at each end. In the less elongate but more ovoid parasite bodies the paranuclear masses continue to be distributed regularly throughout the trophamnion.

THE POLYEMBRYONAL MASS

Between the twenty-sixth and thirty-second days after the egg has been deposited the parasite body represents a typical polyembryonal mass. During this period organogeny of the embryos takes place. The parasite body is usually found intact in one end of the mid-intestine of the host at this time (Pl. 7, B), although occasionally it may become split up into two or three secondary polyembryonal masses.

A twenty-seven day old parasite body is illustrated in Plate 6, B. This parasite body measures approximately 0.52 by 0.19 mm. The embryos continue to be held together by the trophamnion, which is less dense than in the preceding stages. The paranuclear masses have increased in size, but these, too, are less concentrated.

The organogeny of the embryos, as far as has been determined in a general way, takes place similarly to that described by Marchal (*5*, *6*) for *Polygnotus minutus* and other Platygasters and by Silvestri (*9*) for *Platygaster dryomyiae;* and it will therefore not be referred to in detail. The blastulas become somewhat oval (Pl. 6, A) before the embryonic layers are differentiated. Prior to the formation of the mesenteron the embryos assume the U-shape (Pl. 6, B) described for other polyembryonic Hymenoptera, and then straighten out to form the primary larval stage (Pl. 7, B). During organogeny the embryos increase in size from 0.09 mm. in length, when they are somewhat U-shaped, to approximately 0.14 mm., when they resemble typical primary larvæ.

The final stage of the polyembryonal mass is illustrated in Plate 7, B, which represents a section through a parasite body at about the thirty-second day. The parasite body measures 0.8 by 0.4 mm. The embryos are in reality fully formed primary larvæ which have not yet taken any food, and measure approximately 0.23 by 0.07 mm. The fixed host in which this polyembryonal mass is found measures 3.8 mm. in length, while its mid-intestine measures 2.1 by 0.47 mm.

About the thirty-fourth day the membranelike trophamnion is ruptured by the first feeding of the primary larvæ, whereupon the larvæ are set free in the mid-intestine of the host (Pl. 1, D).

SUMMARY AND DISCUSSION OF CLEAVAGE TO LARVAL STAGES

It has been demonstrated above that the egg of *Platygaster vernalis* is organized into a typical polygerm, and finally into a polyembryonal mass, during the course of its later development, and before the newly formed primary larvæ are set free. This development takes place entirely in the mid-intestine of the

host, the parasite body being tossed about within it by peristaltic action, at least until the polygerm stage is formed. Thereafter, the polygerm becomes, as a rule, lodged in one end of the mid-intestine, where the germs develop into true embryos, and finally into the primary larval stage before the parasite body is broken up.

The development of *Platygaster vernalis* is therefore similar, in a general way, to that of *Polygnotus minutus*. In other described polyembryonic species, such as *Copidosoma gelechiae* and *C. truncatellum*, development takes place in the body cavity of the host, the polygerm breaking up into secondary masses which are held together in a group by adipose tissue of the host in the case of *C. gelechiae*, and scattered throughout the body of the host in the case of *C. truncatellum*. Each individual blastula or embryo of *C. gelechiae* and *C. truncatellum* becomes separated from all others and is invested with a portion of the trophamnion and paranucleus, thus completing its development independently of any other individual. In *Platygaster vernalis* and *Polygnotus minutus* the parasites are developed to the primary larval stage in the common original trophamnion, although, as mentioned above, the parasite body may, in a few instances, at least in *P. vernalis*, become accidentally divided into two or three secondary masses. In this event one of these secondary masses may not develop completely.

Before cleavage the egg contains a cleavage or embryonic nucleus in a differentiated embryonic region, the remainder of the egg comprising the trophamnion, which contains two paranuclear masses of polar body origin. Four cleavages of the original embryonic nucleus result in the production of twelve to sixteen daughter embryonic nuclei, each of which lies within a small portion of the embryonic plasm and forms a germ. Some of the germs when composed of eight embryonic nuclei divide to form two daughter germs, but in any event each normal healthy germ finally develops into an embryo. From eight to twelve embryos are thus developed from a single *Platygaster vernalis* egg.

The development of the *Platygaster vernalis* egg therefore represents a simple type of polyembryony; not as simple as that shown by the writers (*4*) in *P. hiemalis*, nor as complex as that demonstrated in other polyembryonic insects by Marchal (*5*), Silvestri (*7*), and Leiby (*3*). In *P. hiemalis* we have shown that immediately after second cleavage some of the eggs divided into two equal parts, each part containing two embryonic nuclei and two paranuclear masses which together form an embryo. Twin embryos are thus developed from some eggs, while other eggs do not become so organized, and develop but a single individual. In *P. vernalis* approximately four cleavages take place before the germs are formed and an average of eight embryos are thus matured from a single egg. In *Copidosoma gelechiae* the senior writer (*3*) has shown that the germs are not organized until after the seventh cleavage, with the result that from 150 to 225 embryos are produced from a single egg. In any event, it appears that the number of embryos produced nearly always approximates the number of parasites that the host larva is able to mature. The size of the host appears to be the governing factor. Where but one egg is normally deposited in the host egg, as in the case of *C. gelechiae* and *P. vernalis*, cleavage continues to the point where the maximum number of parasites is developed that the host can mature. When cleavage extends beyond that number the embryos become aborted in their different stages. In the case of *P. hiemalis* two individuals develop from some of its eggs, and a single individual from others. This parasite therefore deposits from five to eight eggs at a time in one host egg, and in this way are developed the maximum number of individuals of this species that the Hessian fly larva can mature.

The failure of some of the germs to keep pace in their development with other germs in the same host has been briefly referred to above; the fault being ascribed

to cleavage of daughter germs. A similar condition obtains for some of the blastulas, but the instances are rare. Occasionally a group of three or four blastulas will fail to continue development. Examination of the parasite body shows in such instances that a portion of it has become separated in the host intestine from the rest of the parasite body, and that the detached portion did not happen to become provided with a sufficient amount of the trophamnion and paranuclear masses. Such blastulas then become aborted.

Occasionally host larvæ are met with which contain more than one parasite body, in spite of the tendency of the parasite to oviposit in an egg only once, and to deposit at that time only a single egg. At such times one of the parasite eggs may fail to continue development. An undeveloped parasite body of this kind is illustrated in Plate 4, D.

Aborted eggs, germs, blastulas, or larvæ in *Platygaster vernalis* are rare in comparison to those which have been observed in *Copidosoma gelechiae* and in *C. truncatellum*, a condition which is to be expected in polyembryonic insects which show a comparatively simple type of polyembryonic development.

THE LARVA

As has been shown by the junior writer (*1*, *2*) the larva passes through two distinct stages in completing its development. When the insect takes its first food it is known as the primary larva (Pl. 8, A). In this stage the larva is elongate oval, bluntly rounded at both ends, and possesses two relatively large mandibles. This stage is further characterized by a lack of distinct body segmentation, and the presence of two very prominent lateral knoblike projections which are located in the head region at the base of the mandibles. The primary larva measures about 0.54 mm. in length and 0.18 mm. in width.

The mature larva (Pl. 8, B, C) is white, ovoid, and measures about 1 mm. in length and 0.5 mm. in width. Spiracles are present in this stage on the second and third thoracic segments, and second abdominal segment only. The mandibles of the mature larva are less than half the length of those of the primary larva. Eleven distinct body segments are defined in the mature larva.

Feeding commences when the primary larva is fully formed. The larvæ of a brood first consume the remnants of the trophamnion, whereupon they become liberated in the mid-intestine of the host (Pl. 1, D) and ingest the chyle. The intestine is next ruptured and the fatty tissues consumed. In the course of feeding, the entire contents of the host larva are consumed, leaving only the outer cuticle (Pl. 8, C) to contain the fully developed parasite larvæ. In the process of feeding, the superior lip is moved toward and away from the inferior lip by radiating muscles which are quite prominent in the head region.

A parasitized larva very seldom succeeds in pupating, but it does form the puparium. Each parasite larva, when fully grown, forms a cocoon, so that a brood of the parasites in the larval or pupal stages is contained within a cluster of cocoons (Pl. 1, E), which is in turn confined in the puparium of the host (Pl. 1, F).

THE PUPA

The pupa (Pl. 8, D) is formed in the cocoon. At the time of transformation it is white in color, but gradually the eyes and body darken until it is a shiny black. The parasites spend two to three weeks in the pupal stage.

THE ADULT

The adult is shiny black and measures from 0.7 to 0.9 mm. in length. An average of about eight individuals, which are nearly always of the same sex, are reared from one host. After emergence in spring they will live in confinement

from three to twenty-nine days, the length of time depending upon the food and the humidity of the atmosphere.

Oviposition by fertilized or unfertilized females takes place immediately after emergence if the parasite happens to come in contact with a host egg. Experiments conducted by the junior writer (*2*) show a definite tendency for a female to oviposit only once in a host egg. The preparations, studied by the writers, which resulted from ovipositions controlled in the laboratory, indicate conclusively that a single egg is deposited at each oviposition.

SEX RATIO

A study of the sex of individuals of the broods indicates that usually all of a brood are either males or all females. Of 48 broods, 40 were either pure male or pure female broods, and 8 were mixed. A similar ratio has been shown by Marchal (*5*) for *Polygnotus minutus;* in the article cited he records the sex of 16 broods; eight being pure female broods, six male broods, and two mixed. Marchal believes that a mixed brood originates as a result of a fertilized and an unfertilized egg being deposited in the host. The writers believe that a similar explanation will answer for *Platygaster vernalis.*

SUMMARY

(1) *Platygaster vernalis* develops polyembryonically in the larva of the Hessian fly, one egg giving rise eventually to approximately eight individuals. There is but one generation annually.

(2) The adult parasites emerge from their cocoons in spring and almost immediately oviposit in the eggs of the host. By the first of June the embryos are fully formed in a well-grown host larva. The larvæ feed upon the host during June and July, and then transform to pupæ, which in turn become adults in August.

(3) A single egg is deposited by the parasite at each oviposition, and in such a manner that the egg always becomes lodged in the host's mid-intestine, where development to the larval stage is completed. Development begins immediately, whether the egg is fertilized or unfertilized.

(4) If more than one egg is deposited in the same host by different females one of the eggs may become aborted.

(5) In the course of maturation two polar bodies are formed, which become the two original paranuclear masses. The maturated oöcyte or cleavage nucleus becomes the progenitor of the embryos.

(6) Four divisions of either the conjugated or parthenogenetic cleavage nucleus result in the production of twelve to sixteen embryonic nuclei, each of which apparently gives rise to a germ. The germs develop in the central part of the parasite body and are encompassed by the trophamnion containing paranuclear masses.

(7) Some of the germs divide once, at the time they are composed of eight nuclei, to form two daughter germs. A further division of the daughter germs apparently results in the production of pseudogerms.

(8) The group of germs comprising a parasite body is known as a polygerm. Each normal germ passes through the blastula and late embryonic stages, and finally becomes a primary larva. During the course of this development the parasite body increases in size and remains intact in the mid-intestine of the host.

(9) When the primary larvæ are formed they rupture the thin trophamniotic membrane and begin to feed upon the contents of the host's mid-intestine. Later the mid-intestine is ruptured, whereupon the secondary or mature larvæ devour the entire contents of the host, leaving only the cuticula.

(10) Each larva constructs a cocoon in which it transforms to a pupa and later an adult parasite. The cluster of cocoons is surrounded by the cuticula of the host, and is further protected during the winter by the host's puparium.

(11) The adults of a brood are usually of the same sex. It is believed that the occasional mixed broods originate from a fertilized and an unfertilized egg deposited in the same host egg.

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PLATE 1

Platygaster vernalis

A.—Female parasite poised on a blade of wheat and ovipositing in egg of Hessian fly. ×45.

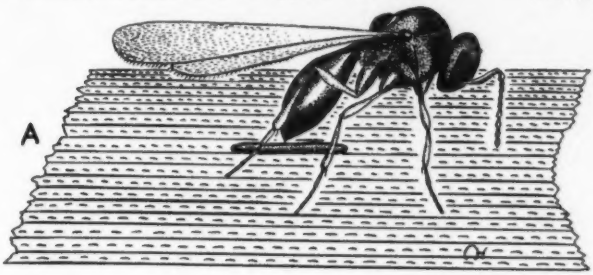
B.—Egg of *P. vernalis* before oviposition. Much enlarged.

C.—Longitudinal section through a young Hessian fly larva, showing a *P. vernalis* parasite body in the mid-intestine. ×55.

D.—Longitudinal section through a well grown Hessian fly larva showing primary stage larvae of *P. vernalis* in the mid-intestine. ×40.

E.—Host larval carcass (cuticula) containing ten *P. vernalis* cocoons. ×15.

F.—Host puparium showing exit holes made by adult parasites. ×14.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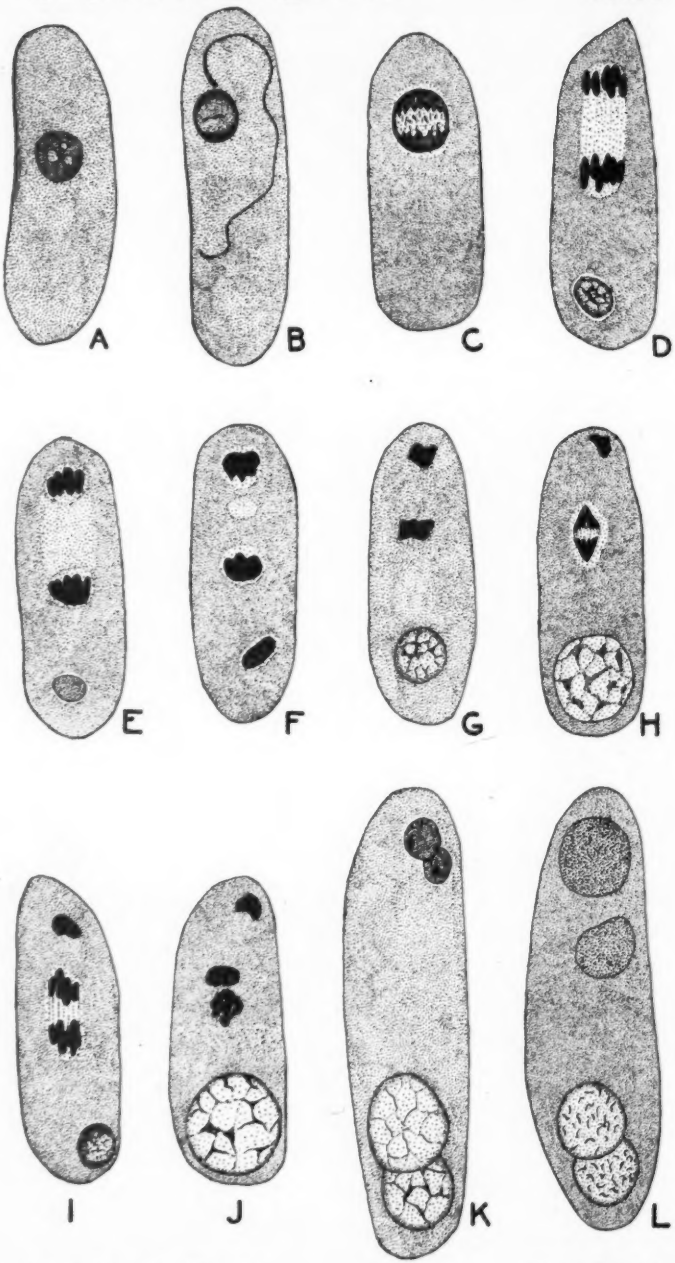
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PLATE 2

Platygaster vernalis

All figures drawn 2,200 times natural size

A.—Unfertilized egg, immediately after oviposition, containing the nucleus.

B.—Fertilized egg 30 minutes after oviposition, with nucleus and vermiform sperm.

C.—Unfertilized egg five hours old, with the nucleus beginning the first maturation.

D.—Fertilized egg six hours old, showing the male nucleus and the first maturation spindle.

E.—Like D, but at slightly later stage. The anterior nucleus becomes the first polar body, the middle nucleus the oöcyte nucleus of the second order.

F.—Like D and E, but slightly further advanced.

G.—Fertilized egg 10 hours after oviposition. The first polar body and the oöcyte nucleus of the second order show their nuclear material much condensed, while the male nucleus has meanwhile expanded and become spherical.

H.—The beginning of second maturation of a fertilized egg, about 12 hours after oviposition.

I.—Like H, but a slightly later stage.

J.—Egg 12 hours old. Second maturation is completed, and a second polar body and the female pronucleus are formed.

K.—Between the twelfth and twenty-fourth hours the egg increases slightly in size. The two polar bodies have migrated to the anterior end of the egg, and begin to increase in size.

L.—Polar bodies become elaborated and are henceforth known as paranuclear masses. Male and female pronuclei about to unite. Egg 24 hours old.

PLATE 3

Platygaster vernalis

All figures drawn 2,200 times natural size

A.—Portion of fertilized egg 24 hours old with male and female pronuclei at prophase.

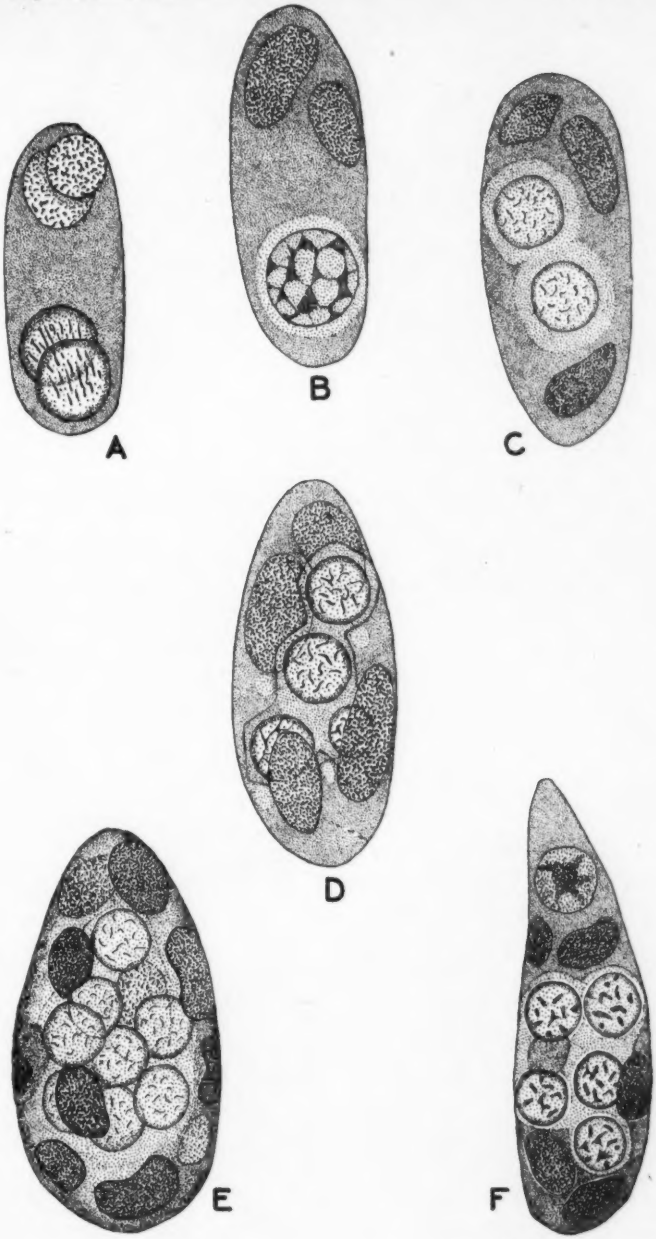
B.—Fertilized egg one to two days after oviposition, with the cleavage nucleus in a differentiated embryonic region. An unfertilized egg of this age has a similar appearance, except that the cleavage nucleus is not quite so large.

C.—Egg (now the parasite body) two to three days old. One of the paranuclear masses has divided amitotically. First division of the cleavage nucleus has produced two cleavage nuclei in a differentiated embryonic region.

D.—Section through a three-day old parasite body, showing four cleavage or embryonic nuclei and four paranuclear masses.

E.—Drawing of entire parasite body four days old. The eight embryonic nuclei are located in a central or embryonic region, which in turn is surrounded by the polar region now known as the trophamnion containing paranuclear masses.

F.—Section of a parasite body about six days old. Five of the eight embryonic nuclei are shown.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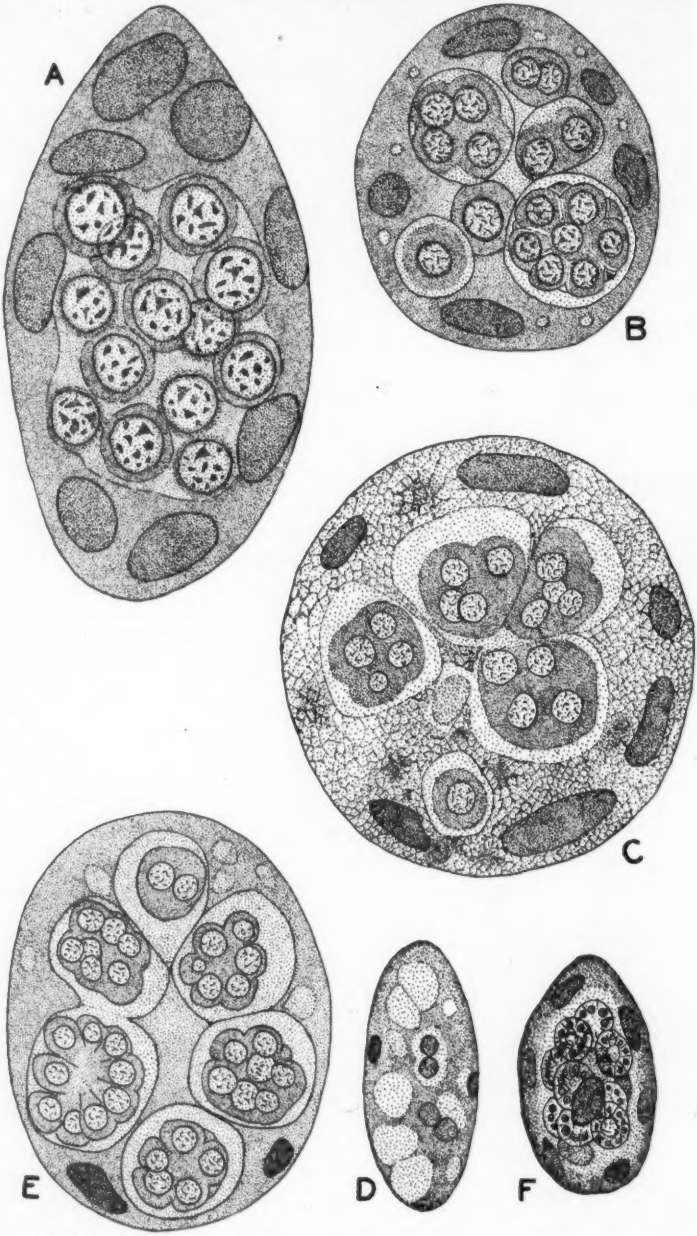
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PLATE 4

Platygaster vernalis

A.—Section of parasite body about seven days old, showing thirteen of its sixteen embryonic nuclei forming germs. The parasite body has increased in size considerably. ×2200.

B.—Section through a polygerm about ten days old, showing five germs and one morula. The darker nuclei in the periphery are paranuclear masses. ×1100.

C.—Section through a polygerm about twelve days old, showing portions of five germs. The two upper germs have just been produced by the division of a parent germ. Each germ is lodged in an embryonic cavity which is surrounded by a somewhat vacuolated trophamnion containing paranuclear masses. Since development takes place in the mid-intestine of the host, no cyst of host tissue ever surrounds the parasite body. ×1100.

D.—Aborted or pseudoparasite body, found sometimes in host with a healthy parasite body, in the process of degenerating. Twelve days after oviposition. ×1100.

E.—Section of a polygerm about thirteen days after oviposition, showing portions of six embryos in the germ or early blastula stage, and two paranuclear masses in the trophamnion. ×1100.

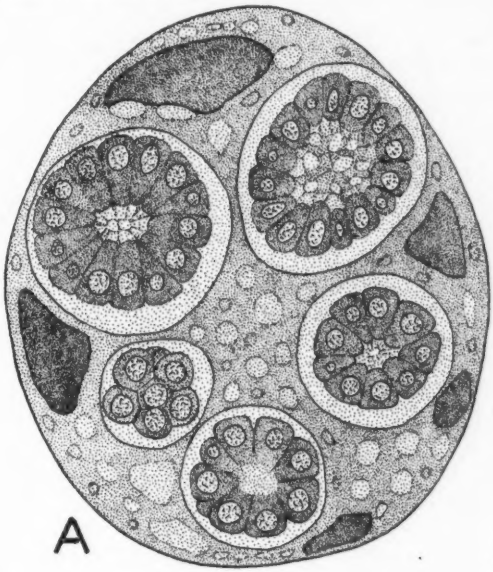
F.—In toto drawing of a polyblastula with nine blastulas in the embryonic region which is surrounded by the trophamnion, containing its dark staining paranuclear masses. ×550.

PLATE 5

Platygaster vernalis

A.—Section through an 18-day-old parasite in the polyblastula stage showing the embryos at the early blastula stage. The trophamnion becomes noticeably vacuolated and surrounds the embryonic cavities on all sides. ×1100.

B.—Section through a 20-day-old parasite body, showing four normal embryos in the blastula stage, two paranuclear masses and two pseudogerms which are apparently degenerating because division of the parent germ was carried too far. ×550.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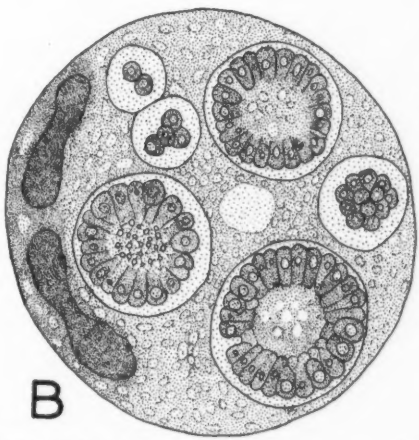
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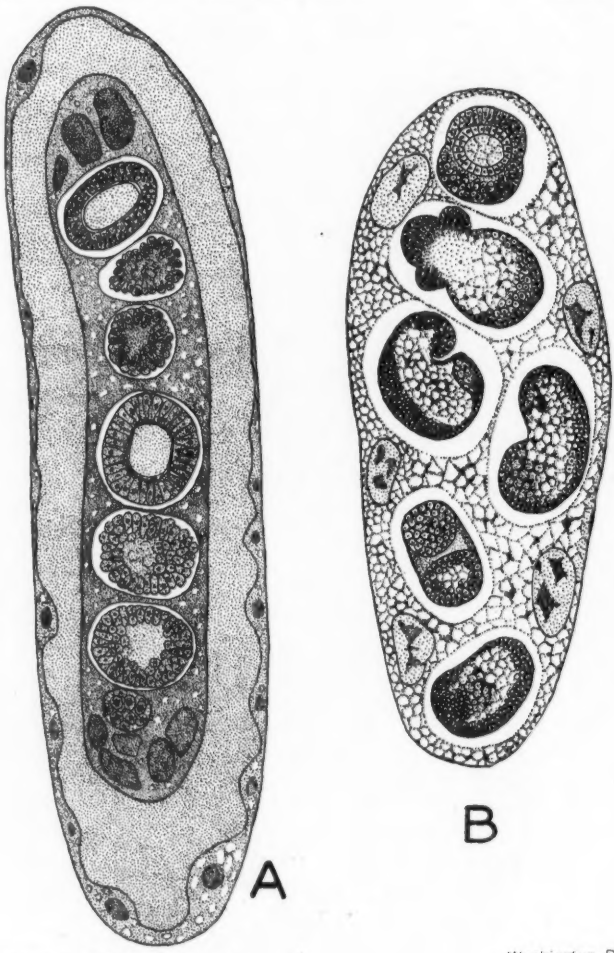
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PLATE 6

Platygaster vernalis

A.—Section of a polyblastula 23 days old located in the chyle of the mid-intestine of the host. Portions of seven of the eight blastulas which compose this parasite body are shown. Two of the blastulas are cut through the center. This parasite body has assumed an elongate shape and now measures about one-fourth the length of the mid-intestine of the host. The paranuclear masses are shown at each end. The periphery of the drawing represents the epithelium of the mid-intestine, the lighter stippled area the chyle of the mid-intestine. ×275.

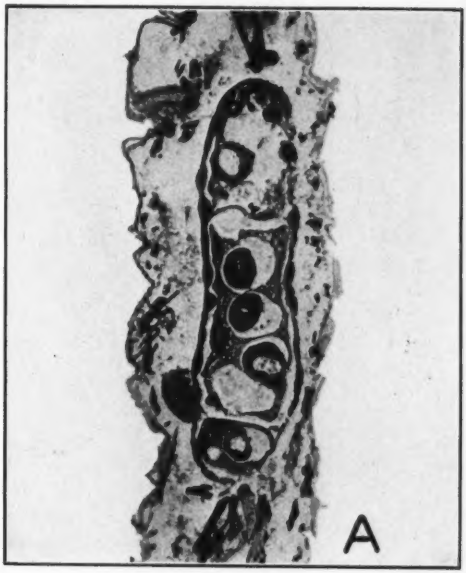
B.—Longitudinal section through a polyembryonal mass about 26 days after the original egg was deposited, showing portions of six embryos. About this time the embryos are forming the germ layers and organs of the young larvae and are somewhat Gothic-like-shaped. Note that the trophamnion is less dense, and that the paranuclear masses are no longer so conspicuous. ×200.

PLATE 7

Platygaster vernalis

A.—Photomicrograph of polyembryonal mass distributed throughout the mid-intestine of the host. Sections of five embryos are shown which have just differentiated the germ layers. Note that the trophamnion is vacuolated. ×93.

B.—Photomicrograph of polyembryonal mass lodged in the anterior end of the host's mid-intestine. The embryos have almost or quite reached the stage of the primary larva. The black area surrounding the embryonal mass represents the chyle of the host. The lower primary larva is just beginning to devour the remnants of the trophamnion. ×62.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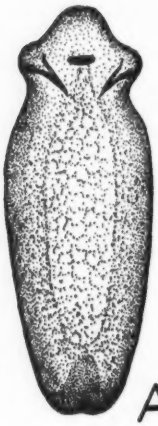

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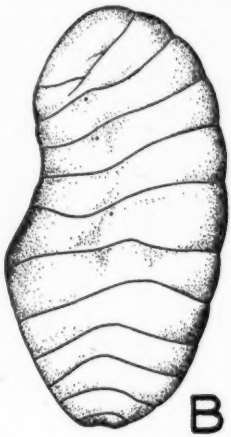

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PLATE 8

Platygaster vernalis

A.—Primary larva. ×111.
B.—Mature larva. ×62.
C.—Photomicrograph of section through a host larva (carcass), showing three *P. vernalis* larvæ that are almost mature. ×25.
D.—Pupa of *P. vernalis*. ×62.

THE INHERITANCE OF PUBESCENT NODES IN A CROSS BETWEEN TWO VARIETIES OF WHEAT[1]

By H. H. LOVE, *Department of Plant Breeding, Cornell University Agricultural Experiment Station, and* W. T. CRAIG, *Agent, Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture*

Nearly all varieties of wheat have glabrous nodes, but there are some which have pubescent (velvet) nodes. One of these was furnished to the authors by J. A. Clark, of the Office of Cereal Investigations. It was a bearded variety with glabrous glumes, which had been found by Ball and Clark as a rather common admixture in a plat of mixed Pacific Bluestem and Baart (Early Baart) wheat on the Adams County Branch Station at Lind, Washington. It was given Cereal Investigations accession number 5877 and, tentatively, the name "Velvetnode." As it does not occur as a commercial variety, it does not appear in the published classification of American wheats. Its most peculiar character was the possession of hairy nodes.

To study the inheritance of the hairy node the Velvetnode variety was crossed with a strain of unknown origin in the plant-breeding nursery. It was being carried under the name "New Columbia" but is not related to the variety grown commercially under that name, which is the same as Fultzo-Mediterranean. The Cornell strain is beardless, has pubescent glumes, and glabrous nodes. This strain has been given Cereal Investigations No. 5946. It is most closely related to Mealy but has very purple stems.

The first generation of this cross resulted in plants that were beardless, with pubescent glumes and nodes. The plants seemed to be perfectly fertile and the heads were well filled with seed.

The seeds from these F_1 plants were sown in the field in the fall of 1921, and the resulting plants were studied during the following summer. Although it had been thought that the Velvetnode was a spring variety, all of the plants seemed to survive the winter and produced fairly thrifty plants.

At harvest time the plants were pulled and sorted first for pubescent nodes only. While there was some variation in the length and number of hairs on the nodes there was no attempt to distinguish between the different types, and all individuals that had any hairs on the node were classed as pubescent. The segregation seemed to indicate a 3:1 ratio with pubescent node dominant. On observing the two lots of plants, however, it was noted that all of the bearded plants were in the group with hairy nodes. No bearded plants were found in the glabrous-noded class. The plants were then reclassified according to the characters of nodes and beards. The results of this segregation are shown in Table I.

[1] Received for publication April 16, 1924. Paper No. 130, Department of Plant Breeding, Cornell University, Ithaca, New York. These results were obtained in investigations conducted cooperatively by the Cornell University Agricultural Experiment Station and the Bureau of Plant Industry, U. S. Dept. of Agriculture.

TABLE I.—*Showing the segregation in F_2 for beards and pubescent nodes*

	Pubescent node		Glabrous node	
	Beardless	Bearded	Beardless	Bearded
Observed	468	202	237	0
Calculated 2 : 1 : 1	453.5	226.75	226.75	0
Deviation	14.5	24.75	10.25	0

These results show that there were no bearded plants with glabrous nodes. The presence of beards usually is due to one factor for beards and the ratio obtained usually is 3 beardless to 1 bearded, and the pubescent-node character occurs in the simple 3 : 1 ratio with pubescence dominant, as described above. Therefore, when the grouping is made according to the two characters one would expect to obtain some plants that were bearded with glabrous nodes unless linkage occurs. In this case the data seem to indicate that there may be a linkage between beards and pubescent nodes. These two characters come in together and out of 907 plants there is not a single case of a crossover type. This also may suggest that beards and hairy nodes result from one factor and that the difference between the parent forms is due to one factor pair. For the present such an assumption will be made.

In respect to the node character the Velvetnode variety may be designated by *VV* and the beardless strain with glabrous nodes by *vv*. The F_1 gametes may then be represented by *Vv*. In F_2 there will be the following types and in the ratio indicated:—1 *VV*: 2 *Vv*: 1 *vv*. The numbers obtained deviated somewhat from the calculated numbers and the value of P is 0.168, which does not indicate a very good fit. When the different plants are tested in F_3, however, it seems that the facts support this 1 : 2 : 1 assumption. There are certain exceptions that will be mentioned later.

According to this assumption, the bearded plants with pubescent nodes (*VV*) all will breed true; the same is true also for the beardless plants with glabrous nodes (*vv*). The beardless hairy-noded plants (*Vv*) all should segregate again into the three types.

Of the F_2 plants, 238 were chosen for testing in the F_3. The numbers from the different classes were as follows: 123 beardless with pubescent nodes, 68 bearded with pubescent nodes, 47 beardless with glabrous nodes.

From the F_2 generation, 123 plants that were beardless with pubescent nodes were tested in F_3. According to the above assumption these would be expected to segregate into beardless glabrous, beardless pubescent, and bearded pubescent, in the ratio of 1 : 2 : 1. Of these plants, 117 segregated in this manner, and, while the number of individuals is not large in some of the families, yet the total number of plants is rather large. The total number is 1,295 beardless glabrous, 2,524 beardless pubescent, and 1,158 bearded pubescent. The calculated numbers for the three classes are 1,244.25 : 2,488.50 : 1,244.25.

There is considerable difference between the calculated and observed numbers. Part of this may be due to the fact that some plants became very ripe in the field before they were harvested (all the notes were taken in the field), and owing to the shattering of some of the awns or beards it was difficult at times to be sure a plant was bearded. The value of P in this case is only about 0.014, which shows a poor fit for a case of this sort. If it were not for the breeding behavior, one would conclude that the deviation from expectancy was too great to substantiate the hypothesis assumed.

In addition to these 117 plants there were certain ones that showed a different behavior. For example, there were four F_2 beardless plants with pubescent nodes whose progeny did not segregate into the three groups as did those of the 117 plants noted above. Two of these plants produced plants with hairy nodes only, but segregated for beards. These produced 76 plants that were beardless with pubescent nodes and 20 plants that were bearded with pubescent nodes. While these numbers are not large, nevertheless in other cases with smaller numbers the expected 1:2:1 ratio was obtained or approached. The other two F_2 plants produced only beardless plants in F_3, but segregated for pubescent and glabrous nodes.

Thus, out of 123 plants of the F_2, 117 reproduced the three types in the expected ratio, 1:2:1, that would follow providing the difference between the parent forms is due to one pair of factors. The occurrence of these six plants that did not give the expected ratio suggests that there may be more than one pair of factors concerned.

From the F_2 generation 68 plants that were bearded and had pubescent nodes were selected to test in F_3. All of the 68 plants bred true to the type selected; that is, all plants produced were bearded with hairy nodes.

There also were 47 beardless plants with glabrous nodes selected from the F_2 generation to test in F_3. All but two of these plants produced beardless plants with glabrous nodes.

The possibility that more than one pair of factors is concerned is further emphasized by the fact that there were two F_2 plants classed as beardless with glabrous nodes that did not breed true to this character, as would be expected, but segregated for beards. These produced 38 beardless plants with glabrous nodes and 19 bearded plants with glabrous nodes. While in the F_2 no bearded plants with glabrous nodes were obtained, yet in F_3 it is seen that some plants of this class do occur occasionally.

In addition to the plants whose behavior in F_3 is cited above, there were five that produced some bearded plants with glabrous nodes, but the numbers were so small that it may be questioned whether they may not be accidental crosses or mixtures of some kind. These plants are being tested further.

The six F_2 plants that have been mentioned as giving ratios differing from the expected ratios may be crossovers; and, if so, the genetic constitution assumed would have to be modified. A very close linkage would be indicated and the difference between the parent forms would be considered as due to two pairs of factors rather than one. It may be possible that these six aberrant plants result from natural hybridization in the field. This, however, is rather unlikely as no simple cross will explain certain of the results. For example, take the case of the two plants that produced all beardless plants in F_3, but segregated for pubescent and glabrous nodes. As a 3:1 ratio for node type was obtained, it is difficult to see how this could arise from hybridization. If true-breeding pubescent-noded beardless types existed, this could be explained by a cross with a beardless glabrous-noded type, but so far no such constant type has been found.

It does not seem wise to conclude that natural crossing may be the cause of these few plants which produce different ratios from the majority of plants found in the same F_2 classes.

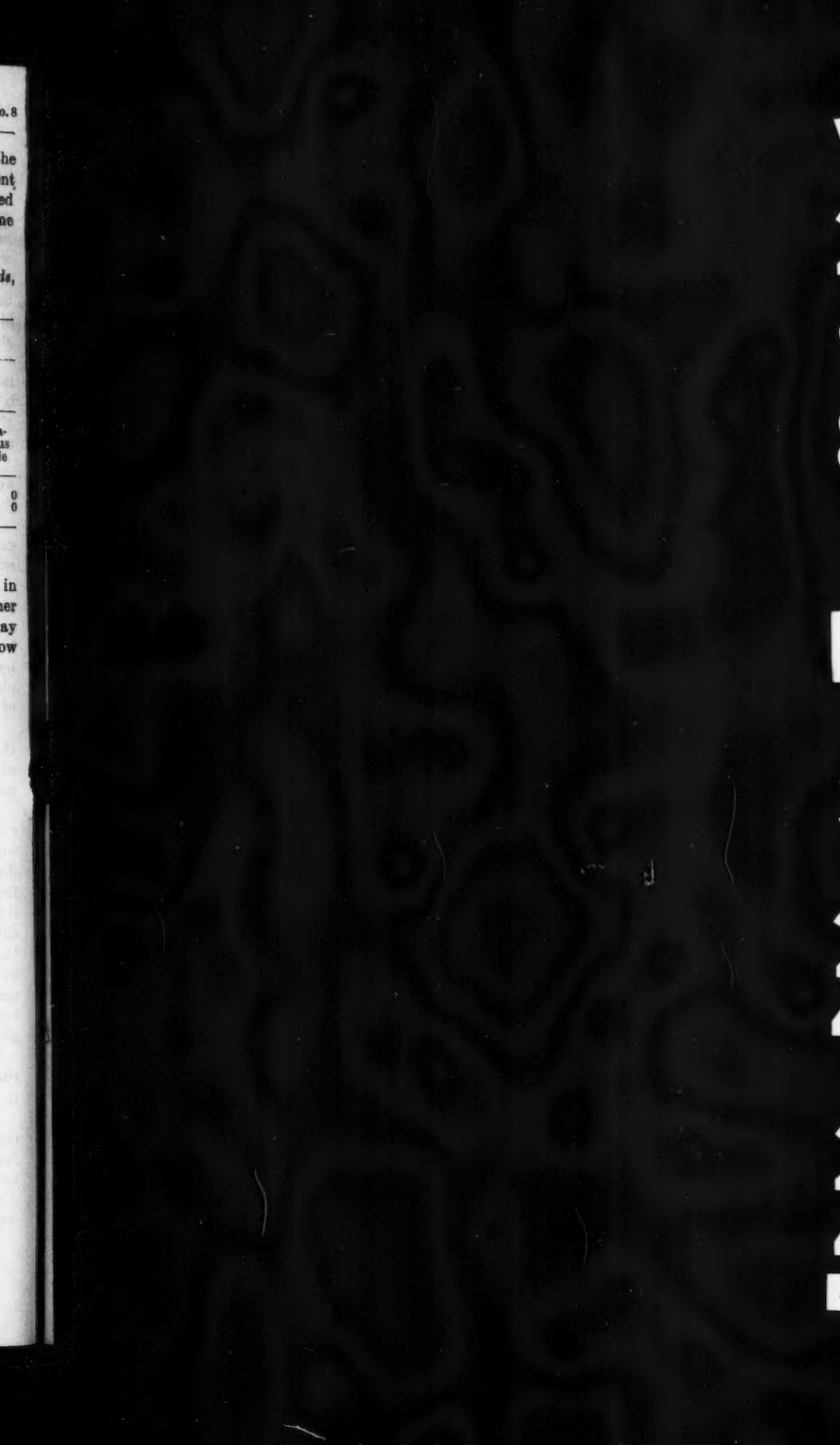
It is possible that they may be explained by mutations occurring in the germ cells, but at present no attempt will be made to assign a definite cause. After further breeding tests, now under way, are finished, a definite explanation can be given.

The plants of F_2 and F_3 also were classified for pubescent glume to determine whether this character segregated independently. The distribution of the F_2

plants for the three characters concerned is shown in Table II, together with the data for 55 F_2 plants tested in F_3. From the results of both F_2 and F_3 it is evident that the pubescent-glume character segregates independently and is not linked in any way so far as this material is concerned. Considering pubescent glume alone, it segregates in a simple 3:1 ratio with pubescence dominant.

TABLE II.—*Showing the distribution of the F_2 and F_3 plants according to beards, pubescent nodes, and pubescent glumes*

	Beardless				Bearded			
	Pubescent glume		Glabrous glume		Pubescent glume		Glabrous glume	
	Pubescent node	Glabrous node	Pubescent node	Glabrous node	Pubescent node	Glabrous node	Pubescent node	Glabrous node
Results from F_2	344	184	124	53	153	0	49	0
Results from 55 F_2 plants in F_3	963	475	355	192	448	0	139	0

CONCLUSION

The results presented indicate that the character pubescent node as found in the Velvetnode variety is very closely linked with the bearded condition. Whether the few aberrant cases are really crossovers or may be explained in another way can not be definitely established at this time. The breeding tests that are now under way will shed more light on this question.